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THE ROLE OF METEOROLOGY IN WATER RESOURCES DEVELOPMENT

By J. P. BRUCE

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THE ROLE OF METEOROLOGY IN WATER RESOURCES DEVELOPMENT

J.P. Bruce

1. INTRODUCTION

1(a) An understanding of the hydrologic cycle is essential to the intelligent management of water resources for man's benefit. Meteorology is directly concerned with many aspects of the hydrologic cycle, particularly the circulation of water vapour in the atmosphere, precipitation and evaporation, and so should be able to contribute substantially to an understanding of the more hydrologic aspect of the cycle, the disposition in time and space of precipitated water. However, it may not be too clear just what the specific contributions may be made, and in what way meteorology may assist in solving water resources and flood control problems. This paper outlines some of these contributions. An approach to water problems through weather information and knowledge is often called hydrometeorology or in the terminology of the World Meteorological Organization "hydrological meteorology".

1(b) It will be seen from the examples in this paper that there are three main stages of water control projects in which hydrometeorological analyses are of value: (i) assessment of economic costs and benefits of a project, relative to alternative projects, (ii) design of control works and (iii) operation of the completed works. In addition, where control structures are uneconomical, river forecasting systems are of great value in minimizing damage and loss of life, and taking greatest advantage of the natural flow of rivers, and here hydrometeorology is of primary importance.

2. FLOOD AND DROUGHT FREQUENCY ANALYSES

2(a) Synthesizing Flood Records from Meteorological Data

2(a)(i) The economic value of a water conservation and flood control project depends on the frequency with which it is needed to overcome the variations of natural water supplies. In addition, in the design of a reservoir, a decision on the size of storage volume required must be based on statistical estimates of likely future high and low water events on the river or lake in question. In countries and regions fortunate enough to have 50 to 100 years or more of river flow and lake level data, such frequency analyses should be

based primarily on river flow data. However, many countries have a great deal more precipitation data accumulated than streamflow data and in such cases methods of estimating flood records from precipitation records are of great value.

2(a) (ii) For watersheds in the range 25 to 5000 sq. mi, storm rainfall-runoff correlations and unit hydrographs can be developed for any period of joint precipitation-streamflow record and these may be used along with the longer records of precipitation in re-constructing previous flood events and thus effectively extending the length of river flow records. Such correlations are also used in river forecasting and usually involve 4 or 5 variables: storm rainfall volume, runoff volume, an antecedent precipitation index or a soil moisture index, a seasonal factor (often the week number of the year), and sometimes a storm duration factor. These correlations can be derived graphically or analytically from recorded events on the river. This approach has been taken to its logical extreme by Paulhus and Miller (1957) who showed that a whole annual maximum flood series for a river could be successfully estimated from regional rainfall data using rainfall-runoff correlations developed for that region, in the absence of any streamflow data for the particular basin in question. Once the annual maximum flood peak series has been synthesized or extended by means of precipitation data, an extreme value frequency analysis by the method of Gumbel (1954) say, will yield the magnitude of the peak flows for various return periods or inversely, various probabilities of occurrence.

2(b) Rainfall Intensities for Drainage Design

2(b) (i) Hydrologic design problems on very small watersheds (5 sq. mi.) include decisions on culvert sizes, design of storm sewer systems for cities, spillways for farm pond dams, and even drainage facilities for roofs. Streamflow data are rarely available for such small watersheds and these watersheds are small enough that their rainfall intensity regimes can be represented by data from one rain gauge. In such cases various formulae such as the "rational method" involving rainfall intensity are used in estimating peak discharges. The rainfall intensity selected for use in the formulae is for a specific frequency or return period. The return period used is dependent on the economics of the situation. Given an estimate of the damage that would be done should the structure's capacity be exceeded by various amounts, and the frequency with which such flows are likely to occur, the most economical design can be achieved. Most storm sewers are designed for 5 to 10 year return period amounts.

2(b) (ii) In many countries not enough observed rainfall intensity data are available to perform frequency analyses for drainage design. In such cases, empirical methods developed by Hershfield and Wilson (1957) may be used. These permit computation of short duration rainfall intensities of various frequencies from one-day rainfall data, and numbers of thunderstorm days. Where limited amounts of rainfall intensity data are available, generalized maps can be drawn after obtaining relationships between the short duration data available and longer duration, 6, 12 or 24 hour data, more generally available. (Bruce 1959). It might also be noted that relatively simple methods for undertaking the Gumbel extreme value frequency analyses, have recently been summarized by Kendall (1959). These methods can be used

for either rainfall intensity or streamflow data. They involve computing the mean and standard deviation of the series of annual maximum values and applying a simple table or graph for computation of amounts for various return periods or probabilities.

2(c) Drought Frequencies

2(c) (i) In connection with provision of storage reservoirs and farm ponds for tobacco irrigation in Southwestern Ontario, an assessment was needed of the frequency with which various volumes of irrigation water would be required, during the critical growth period June 1 to August 15. It was found that the mean storage capacity of the porous sandy soil was about 1 inch. It was assumed that the plants would draw water from the soil at the potential evapotranspiration rate until the soil water storage was completely withdrawn. Day by day soil moisture budget calculations were undertaken for 20 years of record. In these calculations it was assumed that the soil was saturated on June 1, that this water was gradually depleted between rains at the rate of potential evapotranspiration calculated by the Thornthwaite method and that rain added to the storage water up to a maximum of one inch. The sums of potential evapotranspiration amounts after soil moisture had been depleted to zero were assumed to be measures of the amounts of irrigation water that should be applied to the crop. Fortunately, measurements of irrigation volumes actually applied by farmers in the area were available for a few years, and corresponded quite closely to the computed amounts. Then as the 20 years of water deficiencies, so calculated, appeared to be normally distributed about a mean value, normal probability tables were used to predict how frequently various volumes of irrigation water would be required. The economics of providing storage facilities for the 5, 10 or 15 year return period "drought" could proceed from there. More complicated soil moisture budgeting procedures using meteorological factors have been developed by Holmes and Robertson (1959) and other workers, primarily for use in operationally scheduling application of irrigation water.

3. MAXIMUM PRECIPITATION AND FLOODS

3(a) Requirement for Physical Analysis

3(a) (i) Large dams, particularly those constructed upstream from urban centres, must be designed to very stringent safety criteria. In some cases the spillways of such dams are designed to accommodate an estimate of the physical upper limit to flow in the river, or at least are designed in the light of such an estimate. Physical estimates of maximum flood flows are based on determinations of maximum storm rainfall, snow accumulation and snowmelt. An example will serve to illustrate why statistical techniques are not relied on entirely for estimating maximum floods. The Humber River near Toronto was gauged for 10 years prior to 1954, and the highest flood flow this 344 sq. mi. watershed produced was 10,000 cfs. A frequency analysis of the maximum flood flows would have assigned a very low probability indeed to a flow of 40,000 cfs. Yet on October 15, 1954, a 45,000 cfs. flood rolled down the river doing many millions of dollars in damage and drowning 80 people. The storm which produced the heavy rainfall was nearly identical, meteorologically, with a storm which occurred in September 1878, which also caused floods and

devastation in the Great Lakes region but mostly in the United States. In short, a statistical analysis of streamflow data even on a regional basis would not have suggested the need for designing for such an extreme event, but a study of historical storms in the region would have permitted a prediction of the possibility. Experiences such as this have occurred in many regions and have led to a physical approach to estimates of maximum floods in cases where the ultimate in safety is required.

3(b) Rainstorm Analysis Method

3(b) (i) The first step in assessment of the physical upper limit to storm rainfall is to perform depth-area-duration analyses of the rainfall production of major storms of record in the area in question, and in climatologically similar adjacent areas. Analysis procedures are described in a U S. Weather Bureau manual (1946). The table or graph resulting from such storm analyses gives precipitation depth vs. area for fixed durations, usually 6, 12, 18, 24 hrs. etc., during which the areal precipitation was greatest. That is, the data are maximum in a time sense, averaged areally outwards from the storm centre or centres. It is generally assumed that among the storms of record in a region at least one has functioned at near maximum mechanical efficiency in converting the water vapour in the atmosphere into rain. Thus if the rainfall of each severe storm of record is adjusted for maximum moisture content of rain-producing air masses in the region at that time of year, an estimate can be made of the maximum storm precipitation for various areas and durations. The moisture maximization factor can be estimated from dew point data in the absence of upper air observations of air mass water vapour content. (U.S. Weather Bureau 1947).

3(b) (ii) The method applies of course to regions in which travelling extra-tropical storms or hurricane-type storms produce heaviest rainfalls. For tropical regions, and where only a few years of data exist, special techniques have been successfully developed and applied. An example is the study of the Bocono River basin in Venezuela by Riehl and Byers. (1960).

3(c) Maximum Snow Accumulation

3(c) (i) Three methods are available for estimating the upper limits to seasonal snow accumulations, the "partial season" method, snowstorm maximization and the statistical approach. The first of these assumes that one can combine the greatest amounts observed in months, or fortnights, or shorter periods, regardless of the year of occurrence to give a "synthetic" year of very high snowfall. The second method involves applying moisture maximization factors to each snowstorm of several of the larger observed snowfall seasons. The maximized storm snowfalls when summed for the season yield maximum snow accumulation estimates based on the assumption that all the storms could have occurred at maximum water vapour content of the precipitation-producing air masses. A statistical study by a method of extreme values, of annual maximum observed snow depths on the ground, serves to verify results obtained by the other two approaches. In applying these methods to the region of Quebec along the north shore of the St. Lawrence River near Baie Comeau, the figures from the 3 methods tended to corroborate each other

and a value of 200% of greatest observed winter snowfall was determined as the upper limit to snowfall in this region (Bruce 1962).

3(d) Maximum Melting Rates of Snow

In years past the number of degree-days above 32°F (0°C) were frequently used to correlate with snowmelt rates and volumes. More recently a more thorough understanding of the physical factors affecting snowmelt rates has been obtained and basin melt equations derived involving insolation, snow surface albedo, air temperature, humidity, wind and rainfall. (U.S. Corps of Engineers 1956). Preliminary tests indicate the superiority of these basin equations in estimating maximum melting rates (Bruce 1962).

3(e) Maximum Flood Flows

In the ways outlined above the maximum water supply to a watershed from rain and melting snow can be estimated. It remains then, to convert this into a maximum flood hydrograph for design purposes. Rainfall-runoff correlations permit estimation of the proportion of the water supply that will appear in river channels during the peak flood period, and unit hydrograph techniques are applied to determine the distribution in time of this volume of runoff and the peak discharges that will result.

4. OTHER METEOROLOGICAL ASPECTS OF DAM AND RESERVOIR DESIGN

4(a) Evaporation Losses

4(a) (i) In many parts of the world evaporation losses from lakes and reservoirs may be large in proportion to the volume of water stored and must be accurately estimated, preferably prior to the construction of the storage facility, so that suitable allowances may be made for this loss. In Weyburn Reservoir, Saskatchewan, for example, the evaporative loss is approximately equal to the annual consumption of water by the town. The Lake Hefner and Mead experiments (U.S. Dept. of Interior 1954, 1958) in western United States have critically reviewed the various formulae and instruments for estimation of lake and reservoir evaporation. Among the findings were that relatively simple mass transfer types of equations of the "Dalton" form are as suitable as any for estimating lake and reservoir evaporation, in the climatic zone of the experiments. However two main problems remain. How can the surface water temperature of a yet-to-be-formed reservoir be accurately estimated and how well do the Lake Hefner and Mead findings apply in different climatic regions? Energy balance techniques along with limnological knowledge of temperature regimes of small lakes have been successfully used in solving the first of these problems. The second requires research in many parts of the world.

4(a) (ii) One other important development in recent years has been the derivation by Kohler, Nordenson and Fox (1955) of corrections to U.S. Weather Bureau Class "A" evaporation pan data for net heat transfer through the pan walls, to permit estimation of lake evaporation for water bodies of negligible heat storage.

4(b) Wind Set-up and Waves

4(b) (i) Lakes and reservoirs, particularly if shallow and oriented with their long axis in the direction of strong winds are subject to set-up and seiche effects due to winds. There must be enough free-board allowed on earth-fill dams so that water does not spill over the structure under critical wind conditions. Although the state of theoretical knowledge of the wind stress on water surfaces is not entirely satisfactory, enough is known to make reasonable estimates of maximum set-up and wave heights from data on maximum wind speeds in the critical direction. On shallow lakes with long axes parallel to favoured directions of strong winds the water level at one end of the lake may be raised or lowered by as much as 4 or 5 feet by wind set-up. Wave heights on top of this of 3 or 4 feet are not uncommon. The cost of raising a dam 7 or 8 feet for protection against such events is likely to be great. Thus accurate estimates of the maximum magnitude of this effect and the meteorological likelihood of winds required to produce maximum set-up and waves, following meteorological events which would lead to a full reservoir, are essential to economical and safe design.

5. HYDROLOGICAL FORECASTING

5(a) River Forecast Requirements

The day-to-day or month-to-month prediction of instantaneous flows or volume flows of a river may be extremely valuable in many ways. On watersheds where flow is uncontrolled by dams, such forecasts permit issuance of flood warnings as needed, may permit more efficient navigation, log-driving, and regulation of diversions of water for irrigation and other purposes. For controlled or partially controlled rivers, reliable forecasts of river flow permit more efficient use of dams for controlling floods, water supply, power production, maintenance of downstream flow volume and other purposes. This is especially so where reservoirs are of the multi-purpose type. It can be seen that if a dam is to be used for flood control only, all that is required is that the reservoir be left empty at all times to accommodate any flood that may occur. However, if it is to be used for water conservation as well, then a high reservoir level must be maintained to meet the needs of the water users. It thus becomes necessary to know by how much the reservoir level should be lowered, and by what time, in order to accommodate a flood. If drawn too low, the conservation lake level is not restored when the flood is over; if not drawn down enough, the dam's capacity is overtaxed and unnecessary downstream flood damage occurs. The value of accurate forecasts increases with the number of purposes to which the dam is put, and the problem becomes more complex and important if more than one dam per river must be regulated.

5(b) Methods of River Forecasting

The smaller the watershed the greater is the need for a meteorological approach to river forecasting. On small watersheds, of the order of a few thousand square miles or less, the response of the river to a rainstorm or to snowmelt is so rapid that only forecasts based on weather observations or weather forecasts can be issued far enough in advance to be of value to users. On large

rivers, it is possible in some cases to forecast the flow on the main stream by routing procedures applied to river flow observations on the tributaries and in headwaters regions. However even here, if reliable forecasts, from meteorological data, of tributary flows are available, a much greater time advantage can be gained in issuance of main stream forecasts. Headwaters or small watershed forecasts are usually based on storm rainfall-runoff correlations as described in section 2(a) (ii). Runoff volumes for individual storms are forecast by these correlation equations or graphs and converted into river flow and stage estimates by unit hydrograph techniques, which also permit prediction of the magnitude/time of peak flow. Storm rainfall volumes are usually based on observed rainfall amounts. Quantitative rainfall forecasting has not yet developed to a stage where it can be relied upon for river forecasts. However rainfall predictions often do serve to alert rainfall network observers to the need for forwarding information to a river forecast centre. Techniques most frequently used in North America involve the antecedent precipitation index as a measure of the wetness of the basin prior to the onset of a storm. However Kohler (1957) has tested a method for using evaporation data along with antecedent precipitation data to more accurately assess this factor. During non-storm periods as well, evaporation data can assist in forecasting the gradual recession of streams, although this is usually done by means of typical recession curves developed from past flow records at the point in question.

5(c) Special Hydrologic Forecasts

The flow of many rivers is controlled by the level of an upstream lake, and in some cases fluctuations of lake level due to wind set-up and seiches can effect marked changes in river flow. For example on the Niagara River, variations of flow within a few hours from 180,000 cfs. to 320,000 cfs. have been observed as a result of wind-induced fluctuations of the water level in eastern Lake Erie. The Ontario Hydro-Electric Power Commission employs a meteorologist, one of whose duties is to predict the winds on Lake Erie, the set-up and seiches these will induce and the effect on the flow of the Niagara. This in turn affects the amounts of power that can be produced at the Niagara Falls generating stations, and the need for providing power from alternative sources.

6. CONCLUSIONS

This paper discusses briefly only a few examples of the ways in which meteorological theory and data can assist in making efficient use of water resources and in controlling floods or minimizing their harmful effects. It has not been possible to discuss the role of meteorology in surveying surface water resources, weather modification by cloud seeding, seasonal runoff forecasting, reduction of evaporation by mono-molecular films of hexadecanol and shelterbelts, the value of precipitation forecasts in irrigation scheduling, or the role of meteorology in assessing the natural water balance of regions and the modifications to microclimate and the water balance that can be effected by manipulation of vegetation. However, I think it is clear from the limited number of examples discussed that a much greater effort in the field of hydrometeorology is warranted in many countries, and in particular the developing countries of the world. Only with such an effort will we manage the world's vital fresh water resources intelligently and well.

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France

METHODES D'ESTIMATION DE LA FREQUENCE ET DU VOLUME DES CRUES UTILISEES PAR LES HYDROLOGUES FRANCAIS DANS LES PAYS EN VOIE DE DEVELOPPEMENT

Par J. RODIER,
Chef de la Section Hydrologie
à l'Office de la Recherche Scientifique
et Technique Outre-Mer
Chef de la Division Hydrologie
a l'Electricité de France,
Inspection Générale
pour la Coopération Hors Métropole

Les mémoires rédigés à l'intention de la Conférence des Nations Unies sur l'application de la science et de la technique dans l'intérêt des régions peu développées sont des documents de travail. Ils sont publiés tels qu'ils ont été présentés et les assertions et opinions qu'ils contiennent sont celles de leurs auteurs.

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2. Les mémoires choisis pour être présentés en séance spéciale pourront être obtenus à la Conférence dans l'une seulement de ces langues officielles.

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L'estimation des débits de crues exceptionnelles est une opération essentielle pour la plupart des projets en rapport avec l'hydraulique, surtout dans les pays neufs. Dans les régions européennes, en considérant les dimensions des ouvrages qui depuis des siècles ont résisté aux crues, il est souvent possible d'éviter des déboires aux ouvrages neufs sans calculs hydrologiques bien savants. Mais, dans beaucoup d'Etats en voie de développement, des ouvrages aussi anciens n'existent pas et il n'est pas possible d'éviter des études hydrologiques sérieuses. Les désastres accumulés jusqu'ici justifient amplement les efforts à entreprendre pour l'étude des crues, étude difficile et pour laquelle l'hydrologue est assez mal armé.

Les méthodes utilisées varient selon la fréquence des crues qui intéressent le projeteur (fréquence qui résulte elle-même des risques admissibles), la superficie du bassin versant, la nature du régime et les données d'observation dont on dispose. Il est d'ailleurs prudent d'employer plusieurs méthodes et de confronter les résultats.

Les hydrologues Français ont eu la chance d'étudier les climats extrèmement variés de l'Europe Occidentale, des régions méditerranéennes, de l'Afrique Occidentale et Centrale, du Pacifique, du Moyen et de l'Extrème Orient, des Antilles et de l'Amérique du Sud, ce qui leur a permis d'utiliser une gamme assez complète de méthodes de calcul de crues. Il n'est pas question de les présenter toutes, ni de faire une analyse approfondie de chacune de ces méthodes ; on se contentera d'exposer ci-après les grandes lignes de celles qui sont le plus souvent utilisées.

I - CAS des GRANDS BASSINS d'AFRIQUE OCCIDENTALE et CENTRALE -

C'est le cas des fleuves à régime tropical ou tropical de transition, dont le bassin est supérieur à 60 000 km2, et pour lequels on dispose d'au moins une station observée depuis 50 ans environ.

Le caractère régulier des crues et l'existence de corrélations entre les débits de crues de fleuves voisins permettent l'emploi de calculs statistiques directs sur les débits. Les indications que l'on possède sur les crues très anciennes du NIL qui appartient à ce groupe sont d'une aide précieuse, malgré leur caractère plutôt qualitatif.

Le processus de l'étude comprend trois groupes d'opérations essentiels :

a) Vérification des observations limnimétriques, recherches de données historiques, contrôle des jaugeages anciens, exécution de jaugeages de hautes eaux complémentaires afin d'obtenir une courbe de tarage valable pour les crues. Grâce à la forte hydraulicité des dernières années, des mesures de débits complètes ont pu être effectuées pour la crue décennale sur de nombreux cours d'eau. Ce groupe d'opérations extrèmement important est souvent négligé.

b) Ajustement d'une relation statistique à la distribution expérimentale des débits de crues : lois de GOODRICH, de GIBRAT-GAUSS ou de PEARSON III ; ce sont les trois relations les plus employées par les hydrologues Français pour ces régions. On déduit de cet ajustement le débit centenaire ou millénaire recherché.

c) Recoupement avec les témoignages historiques, comparaison avec les cours d'eau mieux connus.

L'application de ces méthodes au NIGER à KOULIKORO a conduit, par exemple, aux résultats suivants :

	GOODRICH	GIBRAT-GAUSS	PEARSON III
- Crue décennale :	7 900 m3/s	7 850 m3/s	7 800 m3/s
- Crue centenaire :	9 600 "	9 600 "	9 500 "
- Crue millénaire :	10 900 "	11 000 "	10 800 "

Cette méthode doit être modifiée lorsque le cours d'eau présente de très vastes plaines d'inondation (NIGER dans le delta central, LOGONE Inférieur). Dans ce cas, l'évaluation des crues exceptionnelles passant dans le lit de la rivière, doit être déterminée par ajustement graphique sur les points expérimentaux. Dans certains cas, la courbe admettrait presque une asymptote.

L'exemple de la dernière crue du CONGO semble indiquer que cette méthode générale ne s'applique pas à ce fleuve. Il est probable que le calcul devrait être mené comme indiqué plus haut pour chaque affluent principal et qu'il faudrait examiner ensuite l'éventualité d'une coïncidence au moins partielle de ces crues.

Bien entendu, la méthode est inapplicable ou d'une utilisation dangereuse pour des régimes très irréguliers, du type méditerranéen par exemple.

Pour des bassins plus petits, dont la superficie est cependant supérieure à 7 ou 8 000 km2, les périodes d'observations dont on dispose sont généralement beaucoup plus courtes. Dans ce cas on évalue d'abord la crue décennale ce qui, grâce aux comparaisons avec des bassins voisins et à l'étude des précipitations, n'est pas très difficile. Notons à cette occasion le grand intérêt des crues de cette fréquence : elles ont une réelle signification et peuvent se calculer assez facilement, alors qu'une crue millénaire est un concept bien théorique. Il est donc possible de disposer d'une base relativement solide pour une fréquence déjà assez faible. Cette crue décennale sera souvent évoquée dans ce qui suit.

On choisit ensuite, d'après des exemples mieux connus, un coefficient de majoration entre la crue décennale et la crue de fréquence cherchée. Pour un même régime, ce coefficient devra être d'autant plus élevé que le bassin est plus petit et les crues plus violentes (en liaison avec la pente et la hauteur de précipitations annuelle).

II - CAS des PETITS et TRES PETITS BASSINS - (moins de 200 km^2)

Il y a 15 ans, la documentation était inexistante pour ce type de cours d'eau. En Afrique et à Madagascar, les projeteurs s'inspiraient des normes européennes. A la Réunion où les crues sont extrêmement fortes, on laissait d'énormes débouchés sous les ponts. On sait maintenant qu'en Afrique Equatoriale, Occidentale et à Madagascar, les débits spécifiques varient de 60 l/s.km2 à 12 000 l/s.km2, ce qui montre bien que les normes européennes étaient insuffisantes dans de nombreux cas et conduisaient à des dépenses exagérées dans d'autres.

Lorsque le réseau routier s'est développé dans des régions difficiles et que des plans de développement ont prévu la constitution de petits barrages, le nombre de ponts et surtout de déversoirs détruits fût considérable. Il devenait indispensable de procéder à des études directes de crues. Ces études ne pouvaient être faites que par la méthode analytique qui comporte un examen détaillé des averses et la reconstitution des crues qui en résultent. Il n'était pas question de procéder, pour chaque petit bassin à des observations complètes sur le terrain, ce qui aurait coûté plus cher en général que le prix de l'ouvrage à construire et aurait duré bien trop longtemps.

La solution adoptée consiste à procéder, d'une part, à une étude générale des pluies et, d'autre part, à l'observation de bassins expérimentaux. On parvient ainsi à dégager des normes. L'étude a été effectuée de façon plus ou moins systématique à l'échelle de 1 ancienne A.O.F. et de l'ancienne A.E.F., soit sur un ensemble de plusieurs millions de km2.

Sur les bassins expérimentaux, on procède à l'observation simultanée des débits et des précipitations, avec étude des répartitions spatiale et temporelle. Ceci nécessite l'installation de pluviomètres, de pluviographes et de limnigraphes, et le maintien sur place d'un spécialiste suffisamment qualifié pendant toute la saison des pluies. Le dépouillement et l'interprétation, effectués en général par la méthode des hydrogrammes unitaires, donne la forme-type de l'onde de crue et le coefficient de ruissellement (ou la capacité d'absorption) pour les fortes crues. Il reste à déterminer, pour la crue décennale par exemple, l'averse décennale et les conditions de saturation. L'étude systématique des précipitations de 24 heures, ou de plus faible durée, est actuellement en cours, mais dans chaque cas particulier, une étude provisoire a permis de calculer l'averse décennale avec ses conditions de saturation. Une grande simplification dans l'Afrique à l'Ouest du CONGO réside dans le fait qu'au point de vue statistique, on peut confondre en pratique l'averse isolée avec les précipitations en 24 heures. Ainsi, il suffit d'analyser les précipitations de 24 heures et de chercher la forme-type du diagramme d'intensité, car il y a bien une forme-type.

Le débit de crue ramené à 1 km^2, ou débit spécifique, varie avec la superficie. Il a fallu donner tous les résultats pour une même superficie. On a choisi une superficie standard : 25 km^2. Pour les bassins plus grands, une seconde superficie de 100 km^2 a été choisie. Pour les plus petits, on hésite actuellement entre 2, 4 ou 5 km^2.

C'est ainsi que les débits de crue décennale ont été déterminés d'après les observations portant sur près de 60 bassins expérimentaux, étudiés soit dans le cadre d'études générales (bassins financés par l'Office de la Recherche Scientifique et Technique Outre-Mer ou par l'ex-Service Hydraulique de l'A.O.F.), soit à l'occasion d'études particulières ; mais ces études ont été exécutées ou contrôlées par le même Organisme et, chaque fois, les études ont été conduites en vue d'obtenir la crue décennale, même si l'objectif principal était différent.

Un tableau des débits de crues décennales, avec indications des facteurs conditionnels correspondants, a été diffusé dans le "Rapport préliminaire sur les résultats de la campagne 1959 en Afrique Occidentale". Une étude plus approfondie a été effectuée pour la Côte d'Ivoire. Enfin, tout récemment, le Comité Inter-Etats d'Etudes Hydrauliques a publié : "Estimation des débits de crues décennaux en régime tropical", par C.AUVRAY, qui a donné une première synthèse avec un ensemble provisoire d'abaques permettant de calculer les crues décennales à partir des données pluviométriques et des caractéristiques physiques du bassin.

Bien entendu, ce travail n'est pas complet ; il y a d'importantes lacunes dans des régions où le nombre de bassins expérimentaux a été insuffisant. Les données pour 25 km2 sont nombreuses, mais elles sont insuffisantes pour 5 et 100 km2. Enfin, si cette méthode donne de bons résultats en Afrique Noire pour la crue décennale, il faut pour la crue cinquantenaire, opérer avec prudence, surtout dans les régions désertiques et subdésertiques où les précipitations cinquantenaires sont mal connues, et dans les zones où les sols sont tels que le facteur "saturation" est plus important que le facteur "précipitations".

III - CAS des BASSINS de SUPERFICIE MOYENNE - (200 à 6 000 km^2)

En Afrique Noire, les crues exceptionnelles de ce genre de cours d'eau sont encore mal connues ; le type de précipitations qui leur donnent naissance est tel que la méthode précédente est inapplicable ; le nombre de stations observées directement depuis seulement quelques années est dérisoire, sans que l'on puisse entrevoir à bref délai une amélioration. Les études pour aménagements rizicoles, qui correspondent souvent à des superficies de 500 à 2 000 km^2, sont effectuées actuellement avec un caractère scientifique et intensif, de façon à essayer de dégager des méthodes et des ordres de grandeur pour les bassins de cette catégorie. On a bien tenté par endroits de construire des courbes théoriques de variations du débit de crue spécifique avec la superficie, en s'appuyant sur les données des très grands bassins et des très petits bassins, par exemple pour le NIGER Supérieur, mais de telles courbes sont rares et leur utilisation est extrêmement délicate. Cette méthode se rattache à l'emploi de formules empiriques, type MYER : $Q = c\ A^n$ (A : superficie du bassin versant, Q : débit en m^3/s) mais, pour déterminer les coefficients pour une fréquence donnée, c et n, il faut des données d'observations suffisantes qui sont très rarement disponibles en région en voie de développement ; il n'est donc pas possible de disposer de telles formules, ni d'utiliser des méthodes de corrélation ou de transposition. Des solutions seront certainement trouvées dans quelques années; actuellement, il n'y a guère de méthodes générales et les résultats que l'on obtient sont encore bien incertains.

IV - CAS de MOYENS ou GRANDS BASSINS avec PERIODES d'OBSERVATIONS ASSEZ LONGUES et REGIMES IRREGULIERS -

Il s'agit de régions telles que le Sud de Madagascar, les parties méridionales de l'Amérique du Sud, où les crues exceptionnelles résultent, comme en Amérique du Nord, de précipitations du genre cyclonique durant plusieurs jours ou même 15 jours à 3 semaines et couvrent de très grandes surfaces. On utilise alors une méthode qui rappelle un peu celle des petits bassins. Une étude générale des précipitations permet d'estimer soit un épisode pluvieux de fréquence très rare, soit un épisode pluvieux supérieur à ce qui est possible. Puis on reconstitue la crue par des méthodes analytiques complexes, telle que la méthode de LARRIEU utilisée en France. Elle consiste à décomposer le bassin versant en bandes isochrones sur lesquelles est délimité le ruissellement pour chaque tranche de précipitations, et à reconstituer la crue en rassemblant, compte tenu des temps de parcours, les apports des principales bandes pour l'ensemble de l'épisode pluvieux. Une telle méthode a été utilisée par exemple pour le calcul des crues du Rio NEGRO en URUGUAY. Elle se rattache à certaines méthodes américaines dans lesquelles la précipitation "impossible" est déterminée sur des bases hydrométéorologiques beaucoup plus sûres, mais ceci suppose des données météorologiques qui ne sont pas disponibles dans beaucoup de régions en voie de développement.

V- CAS des TRES PETITS BASSINS en REGION de TRES FORTES PRECIPITATIONS CYCLONIQUES (Antilles, Réunion, Est-Madagascar, îles montagneuses du Pacifique) -

Il s'agit de régions où les précipitations annuelles varient de 4 000 à 12 000 mm et où les précipitations de 24 heures peuvent atteindre et dépasser 1000 mm. La méthode employée consiste à établir la courbe-enveloppe des précipitations maximales mondiales en fonction de la durée et à appliquer la méthode des hydrogrammes unitaires avec un coefficient de ruissellement extrapolé à partir des données des quelques bassins expérimentaux installés dans ces régions. Il est d'ailleurs compris en général entre 75 et 90 %. Ceci a déjà été appliqué à la Réunion où une étude systématique des crues exceptionnelles a été entreprise, et en Nouvelle-Calédonie. Bien entendu, la méthode est inapplicable lorsque le terrain très meuble conduit à la création de barrages naturels dont la rupture créé la crue exceptionelle.

VI - ENFIN, il RESTE le CAS DESESPERE des MOYENS et GRANDS BASSINS à REGIME IRREGULIER et DONNEES d'OBSERVATIONS INSUFFISANTES -

Il est possible d'effectuer des comparaisons directes des bassins analogues soumis au même régime et mieux connus. Pour l'emploi méthodique de telles comparaisons, on dessine une courbe-enveloppe des débits spécifiques en fonction de la superficie du bassin. En coordonnées logarithmiques, une telle courbe est généralement une droite, mais pour ne pas perdre de vue la notion de fréquence, il est avantageux de porter d'abord la droite correspondant à la fréquence décennale qui, elle, peut être déterminée avec une certaine sécurité ; puis on dessine comme on peut la courbe de fréquence plus rare ou la courbe plafond en s'inspirant de la forme de la courbe décennale, en tenant compte de la position des points les plus élevés et en veillant à ce que l'écart entre les deux courbes ait une valeur vraisemblable. Il est bon de veiller à ce que les points représentatifs correspondent à des cours d'eau ayant le même régime de crues exceptionnelles. Cette méthode a déjà été utilisée pour déterminer un ordre de grandeur des crues exceptionnelles de l'IKOPA et de la BETSIBOKA à Madagascar. Elle demande une grande expérience si l'on ne veut pas arriver à des résultats aberrants.

Cet exposé met en évidence la grande variété des méthodes d'estimation utilisées ; il montre aussi la nécessité d'un travail considérable sur le terrain : études de bassins expérimentaux, exploitation du réseau général hydrométrique, pluviométrique et pluviographique avec contrôles fréquents et campagnes systématiques de mesures de hautes eaux. Tout ce travail doit être fait dans le cadre d'un Service Hydrologique, sans attendre l'étude des grands projets d'aménagement, barrage ou réseau d'irrigation, car à ce moment-là, il est trop tard pour entreprendre des observations hydrologiques.

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Agenda Item: A.5.1.4

Nigeria

THE TRAINING OF GEOLOGISTS, MINING ENGINEERS AND SUPPORTING TECHNICIANS

By J.G. SMITH, Dip. Mining,
A.M.I.M.E., Mine Manager's,
Certificate (First Class),
Technical Teachers Certificate,
Lecturer in Coal Mining,
Nigerian Coal Corporation

Papers have been contributed to the United Nations Conference on the Application of Science and Technology for the Benefit of the Less Developed Areas as working papers for that Conference. They are published as presented by the contributors, and the contents and the views expressed are those of the contributors. (See notes overleaf.)

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Introduction

1. Mining is not very extensive in Nigeria and for the purpose of this paper mining is considered to take place in two areas only:

(a) At Jos in the Northern Region where some 30,000 people are employed mostly in tin mining from alluvial deposits.

(b) At Enugu in the Eastern Region where some 3,000 people are employed in underground coal mining.

2. In the North few Nigerians are qualified mining engineers with qualifications which would be internationally recognised. Most of the personnel employed in running the tin mining companies are expatriates.

3. In Enugu only a few expatriates are now employed in running the mine, and of the four colliery managers three are Nigerians. The Nigerian Coal Corporation has enough Nigerians qualified to run its mines or to meet any expansion in the future.

4. Under the plan to develop Nigeria the exploitation of her mineral resources will need to be given serious consideration and so far the following projects are under consideration:

(a) Exploiting the iron ores by setting up an iron and steel industry.
(b) Exploiting the lead-zinc deposits at Abakaliki (Eastern Region).

Many more projects will be suggested, many more mineral deposits will probably be discovered and many more mining engineers and supporting technicians will be required in the future.

5. Under the present system of recruitment mining personnel are made available by:

(a) Recruiting qualified expatriates.
(b) Sending indigenous personnel overseas to obtain the required qualifications.

These methods of recruitment can only be short term policy and are satisfactory while only relatively small numbers of engineers are required. When the country claims to be developed then the method of recruitment is better if personnel are employed from engineers trained in the country concerned since:

(a) This method is cheaper where large numbers of trained personnel are required.
(b) The personnel will have studied the conditions existing in their own country and would not need the period of readjustment required by personnel trained overseas.

6. This paper will now consider the existing facilities available for training of geologists, mining engineers and supporting technicians in this country.

PRESENT TRAINING FACILITIES

The Training of Geologists.

7. The fact that there are very few Nigerians who are trained geologists has now been recognised and the work has now been taken in hand by the University of Nigeria who now have a department of geology at (Nsukka). The problem will be whether enough candidates will be forthcoming who have studied the requisite subjects at school (i.e) physics, chemistry, biology etc., since science seems to be a neglected subject in Nigerian schools. However, the setting up the geology department at university is an attempt to meet the need for trained indigenes and is a move in the right direction.

Training of Mining Engineers.

8. There is no department or institution in Nigeria which trains mining engineers who would be internationally recognised, nor is it possible to date to qualify through a course of training to become a mine manager of a tin or coal mine. The courses available in mining at present only supply the mining industry (tin and coal) with junior mining personnel and junior inspectorate (tin mining).

Tin Mining.

9. The Federal Mining School, Jos provides a course of training in mining with

particular reference to alluvial tin mining. The course is of two years duration and is a full time course. Students come from the tin mining companies and from the Mines Inspectorate department. On gaining the diploma from the school students from the mining companies then proceed to the field to gain practical experience and after this he may take the section 38 (mines act) managers examination to qualify for a certificate of mine management. The inspectorate personnel come to the school as technical officers and on gaining the diploma may be considered for promotion to junior inspectors of mines.

10. The school is well housed and has reasonable laboratories, extensions are being made under the six year development plan. The mineral dressing plant attached to the school is very well equipped with expensive ore dressing equipment for treating the tin sand.

11. The personnel at the school consist of a Nigerian principal, one Nigerian full time instructor, one expatriate part-time instructor who also runs the mineral dressing plant for the treatment of ore, one expatriate part-time instructor who also acts as chemist for the mines department.

Coal Mining

12. The Nigerian Coal Corporation at Enugu undertakes the training of its own personnel engaged in mining as far as is required to qualify for the Nigerian Second Class Certificate of Competency (Under-managers Certificate). Efforts are being made to introduce a mine managers (coal) certificate or Nigerian First Class Certificate of Competency. The course run by the Coal Corporation is of five years duration for the second class certificate and students attend classes on two days per week and spend the rest of the time in gaining practical experience. If the Nigerian First Class Certificate of Competency comes into being the course will be extended by either one or two years thus making the course a six or seven year one.

13. The mining school is badly housed and ill equipped to study the basic or mining subjects of the curriculum. It is doubtful whether the school is sufficiently well equipped to take the students through the first three years of the course.

14. The mining school personnel consists of one full time expatriate lecturer.

Supporting Technicians

15. Of the technicians who support the mining engineers in keeping the mines operating only the mechanical and electrical engineering staff receive any theoretical and practical training for their jobs. The practical training is given in the form of an apprenticeship and theoretical training in engineering principles can be obtained at the local Government Technical Institute where City and Guilds Certificates can be obtained in certain engineering subjects. The Institutes are endeavouring to introduce courses leading to O.N.C. certificates in engineering subjects. These courses are usually taken by means of evening study since part time day courses are non existent at these Institutes.

Conclusions

16. The only training given within Nigeria to mining personnel is:

(a) Through the Nigerian Coal Corporation's Training scheme.

(b) At the Federal Mining School, Jos.

Neither of these schemes produce personnel who would be universally regarded as trained mining engineers.

17. Nigeria is reliant upon expatriate mining engineers and indigenous mining engineers trained overseas for the exploitation of her mineral resources.

18. The amount of mining carried out at present probably does not justify any alteration in the present system of training. However, if mineral resources are to be fully exploited and mining carried out on an extensive scale, there will be a need for a definite policy on the training of mining engineers. This could probably be done by the Federal Mines Department making itself responsible for the training of mining engineers for Nigeria as a whole or the forming of a mining department at one of the existing colleges of technology or universities.

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Agenda Item: A.5.2.1

Portugal

APPLICATION OF THE TURAM ELECTROMAGNETIC METHOD TO PYRITE AND COPPER PROSPECTION IN SOUTHERN PORTUGAL

By J.L. GUIMARAES DOS SANTOS
and Fernando Jose DA SILVA,
Mining Engineers
of the Serviço de Fomento Mineiro

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A.5.2.1 APPLICATION OF THE TURAM ELECTROMAGNETIC METHOD TO PYRITE AND COPPER PROSPECTION IN SOUTHERN PORTUGAL

by

J. L. Guimarães dos Santos
and
Fernando José da Silva
Mining Engineers of the Serviço de Fomento Mineiro

1 - INTRODUCTION

The Serviço de Fomento Mineiro (Mine Development Service) is a department of the Direcção-Geral de Minas e Serviços Geológicos (General Direction of Mines and Geological Survey) that was created with the principal aim of estimating the ore reserves of metropolitan Portugal. In its program pyrite and copper ore prospecting was included.

Pyrite and copper are in fact raw materials vital to modern civilisation. Pyrite is fundamental to sulphur and sulphuric acid manufacture; copper in spite of its present over-production is a metal whose consumption has increased considerably.

Taking in consideration this increase of demand the prospection of new cupriferous areas was activated and more ore was extracted from operating mines. Thus the continuous rise of consumption in the civilized parts of the world and the raising of the standart of living in the less developed ones, should in the future lead to a still more intensive search.

Owing to this, prospecting for new pyrite loads was started by the Serviço de Fomento Mineiro some years ago, sometimes in close collaboration with the mine owners. The development of old copper mines and further copper prospection was also done. Geophysical methods were used, specially the Turam electromagnetic method.

2 - PORTUGUESE PYRITE BELT

It is traditionaly known as the portuguese pyrite belt an area of about 120 km long with a medium width of 20 km that, being part of the Alentejo peneplane, goes from the atlantic coast to the spanish frontier prolonging itself into the neighbouring country.

Its substractum is mostly formed by Devonian and Carboniferous schists, schist-sandstone and schist-graywack series and by many eruptive formations lying in concordance with the sedimentary rocks. As pyrite orebodies are in direct relation with the hypogenic rocks, the mapping of these rocks was considered of the utmost importance and so this work was previously done.

In this area Louzal, Aljustrel and S. Domingos orebodies and three others of less economical importance are known since many years ago, having been discovered, every one of them, by their gossan. The higher consumption of pyrite pointed to an acceleration of the development of known orebodies and to eventual discoveries of new ones, being the Serviço de Fomento Mineiro responsability, part of this campaign. Concrete results could be expected by the application of geophysical methods, geological surveying and mining works taken as a whole. In the zones that were considered to be favorable to the discovery of new orebodies geophysical methods began to be applied.

In view of the high conductivity of the ore, of the experience of this method in similar circunstances and of the rapidity with which the ground can be covered the Turam electromagnetic method was used as reconnaissance method. Electrical resistivity and spontaneous polarization would be used as subsidiary methods.

The 1944-49 campaign was technicaly directed by the swedish campany Aktiebolaget Elektrisk Malmletning (ABEM), owner of the Turam patent. The results of this campaign pointed to the execution of some mining works - mostly drill-holes - to discover the causes of some of the most important anomalies. After these works having been finished by the Serviço de Fomento Mineiro in areas not covered by mining properties, it was concluded that carbonaceous and graphitic schists, sometimes with pyrite impregnations, were responsible for the anomalies found.

Among the electromagnetic anomalies found, a serie of anomalies indicated a small depth conductor between the S. João do Deserto and Algares orebodies, in Aljustrel. As the anomalies were inside a mining property the operating company choosed, as the law permits, to do itself the proposed mining works, discovering in this zone an important pyrite orebody.

The negative results obtained in the other works done to analyse the cause of other anomalies, does not exclude the possibility of existing pyrite orebodies not only in the prospected areas but also, in a general point of view, in the whole pyrite belt.

It is true that the detecting depth of the method is relatively small and that other causes as wide carbonaceous and graphitic schists, and sandstones formations with high humidity percentage, may obliterate eventual pyrite orebodies.

The continuity of the formations, its distance from the surface and its width the greater this influence, changing the characteristics of the electromagnetic anomalies and hindering their interpretation and judicious selection. And near or in the vicinity of these orebodies graphitic schists formations are frequent. Owing to all this, gravimetry and geochemistry are to be used by the Serviço de Fomento Mineiro to study the geological favorable areas where anomalies whose character rends difficult a correct interpretation were found.

Besides those that outcrop in the pyrite belt, other porphyries that change laterally into diorites from Montemor-o-Novo to Serpa are found northwards and seem to be related with the cupreous pyrite orebodies of Caeira and Cabrela. Also southeast of Cercal do Alentejo porphyry formations were mapped, with apparent connections with ferromanganesiferous mineralisations and with orebodies of the B.G.P.C. group that are directly or undirectly related with those mineralisations. It is therefore not a bold assumption if the possibility of existence of eventual orebodies in those zones is admited, furthermore if we consider that some spanish geologists have the opinion that the average width of the pyrite belt is 40 km, as in Spain owing to a greater number of known orebodies, this width is easier to estimate.

a) - Prospected areas and works done in the anomaly zones.

In S. Domingos mine an area of 88 km2 was prospected, 65,726 stations being observed. Most of the anomalies found seem to be related with geological contacts. Anomalies that could be related with orebodies were not detected. Only in the mine of Chança, in the vicinity of some ferriferous outcrops, strong anomalies were found, possibly related with pyrite ore. A 40 m crosscut was opened from the surface, in a zone decidedly related with the anomalies, but only porphyries partly mineralised with pyrite were found, this being a result that did not encourage further work.

Afterwards the operating company did a small experiment with gravimetry in this area but the results seem to follow the topography. Years later the same company started a geophysical campaign in the area of S. Domingos using different methods with geochemistry as reconnaissance method. Anomalies were found again in connection with the electromagnetic anomalies already observed. Some drill-holes were made and pyrite lenticules were cut.

In the zone of Alcaria Ruiva an electromagnetic campaign was carried out in 1950 by AREM, working for Mason & Barry, operating company of the mine of S. Domingos. An area of 43.2 km2 with 22,838 points of observation was covered. Great interest was not given to the anomalies found since they seemed to reflect the structural conditions of the zone.

In the vicinity of Aljustrel an area of 178 km with 192,482 points was prospected. Mine anomalies were found but only those located in the mangenese mine of Herdade da Barradinha, in Curral dos Cavaleiros and in Cerro do Carrasco were choosen to be investigated by direct methods. Drill-holes opened in the first two zones were negative. In the Cerro do Carrasco area, in the S. João do Deserto, and in Algares and near the former in a schist lenticule inside the porphyric formation a very strong anomaly was found. On the Serviço de Fomento Mineiro indications, the property owner opened a shaft in the zone that was completely devoid of surface signs. This shaft went through pyrite at a depth of about 14 meters and arrived at the footwall of the orebody at the depth of 32 m. The load was prospected at this level by galeries and rises these being located in profiles with anomalies, and an orebody with an aproximate length of 100 m and with a maximum width of 7 m and an average width 3,6 was exposed. At the same time a drill-hole program was carried out and showed the existence not only of the above mentioned orebody but also of another - Moinho orebody - even greater and in the approximate, direction of the first and also related to it.

After preparatory works the ore proved in this two new orebodies amounted in the beginning of 1962 to 14 million tons. This quantity represents 61 % of the total proved ore of the mine (1).

Upon porphyry outcrops in the region of Castro Verde an area of 220 km2 with 162,027 points was prospected. Most of the many anomalies found, seemed to be related to the geological structure of the zone and among them those that looked more promising were chosen for drilling. The anomalies were due to graphytic and carbonaceous schists.

The region between the mines of Caveira and Louzal was prospected with 108,269 observation points covering an area of 90 km2. In the southeast contact of the porphyry band that lies between those two mines, more developed anomalies were found. The region between the mines of Caveira and Louzal was prospected with 108,269 observation points covering an area of 90 km2. In the southeast contact of the porphyry band that lies between those two mines, more developed anomalies were found. Some drill-holes were made near the Louzal orebody and graphytic and carbonaceous schists were found to be responsible for the electromagnetic variations.

With the intention of studying the zone between Aljustrel and Alcaria Ruiva an E.M. prospection was made in two adjoining bands whose directions were adapted to the geology of the zone. The area covering the village of Albernoa was prospected in 43.2 km2 with 36,482 observed stations. From all the anomalies found a group 300 m in length in the approximate schist-porphyry contact was selected and will be studied later.

In the other band, more to the southeast, an area of 45.3 km with 25,354 observation points was prospected. The small anomalies found seem to reflect geological conditions, such as contacts between different formations.

3 - CUPRIFEROUS ZONES

The copper mines of Alentejo have been known for many years, specially in the regions of Barrancos, Vila Viçosa and Almodovar. Owing to this, the Serviço de Fomento Mineiro decided to begin the study of these mines by stages. Though in a

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(1) We should like to take the oportunity to thank the mine owners at Aljustrel for the information so kindly furnished.

first approach of the problem it does not seem possible the use of the E.M. method in this cupriferous orebodies owing to the mineralogical constitution of ore, simple experiments made on samples taken from old tips showed that sometimes there existed continuity in the good conductor minerals in spite of the quartz-carbonate gangue of the ore. It was also known that argilaceous material was present in the dykes and so it was thought possible that the deposit could be a better conductor medium than the adjoining rocks. On the other hand it was known that the frequent presence of graphytic and amplytic schists was inclined to obliterate the indications due to the orebodies that, owing to their smaller mass, would be less high, while the true conditions of carbonaceous schists genesis were not known.

After considering every factor and owing to the fact that geophysical methods when directly applied by the Serviço (2) are not excessively expensive, a trial on a restricted area was decided upon. An area of 10 km2, in the region of Barrancos, was chosen. In this zone copper ores were already known. The data obtained showed that it was worth while to enlarge the area in the same region and to prospect other zones by using this method.

a) - The zone of Barrancos.

In this zone two bands were prospected. One of them has a surface of 18.5 km2 with 19,896 observed stations. Four series of principal E.M. anomalies were found, one of them more outstanding than the others, having a total length of more than four kilometers and divided into various branches, and being generally characterised by low indications either in the field quotients or in the phase differences. Nevertheless - and in this lies its chief value - every old mine workings are located in close relation with these anomalies. Owing to this, it was concluded that they corresponded to one cupriferous dyke and to its ramifications.

The other three series of E.M. indications are very strong anomalies with irregular contours and follow the direction of the geological structure of the region and seem to correspnnd to contacts between different geological formations.

The other prospected band had an area of 29.0 km2 with 17,423 points. Some very strong anomaly series not only in the field quotients curves but also in the phase differences were found, following the general direction of geological formations. Nevertheless, in some cases, the anomalies follow with precision the alignment of the old mine workings.

From the observations made we may put forward the hypothesis of the occurrence of ores in concordance with the stratification. But, by their aspect, the anomalies must be caused either by strata of graphytic or carbonaceous schists or by a much altered basic rock that outcrops here and there.

Other E.M. surveys were made in limited areas of the zone. In a place called Courelas, where a small cupriferous dyke was known, an area of 0.2 km2 with 216 observed stations was prospected; in the mine of Serra da Botefa an area of 0.6 km2 was covered with 319 observation points; and in the mine of Piorneiras an area of 0,7 km2 was observed, with 360 stations; no interesting anomalies were observed in any of these areas.

b) - Zone of Almodovar.

In an area covering the Porteirinhos, the Misericordia and the Brancanes bands a total surface of circa 37.8 km2 was prospected with 61,354 observation points. Anomalies were found and some of them were selected for future study on account of their amplitude, their situation near or in alignment with known orebodies and by being found near the schist-porphyry contact, good for mineral deposition. From all the anomalies, a group of small anomalies stand out due to the fact that they are near a big dyke of quartz with cupriferous mineralizations upon which some

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(2) In the 1944-49 campaign the cost per point was Esc. 11.45 while in the campaigns made since 1955 up to now, directly executed by the Serviço de Fomento Mineiro, was only of Esc. 3.60.

claims had been staked. It seems that it follows a fracture and its ramifications in which the quartz dyke is to be found.

If in some cases but not rarely, the small E.M. anomalies are low and not very clear, in other cases are very evident.

In the prospected structure with an average direction of true N 30º W and with the approximate length of 5,500 m, as can be concluded by the geological survey, there is a rejection of over 300 m. The eastern part seems to have been moved southwards, in relation to the other part.

In the middle of the porphyric formation three series of anomalies were found, with the average direction of true N 55º W, related with prospecting works for barytes. These series of E.M. indications are small but evident anomalies related with barytes mineralized dykes.

Other E.M. surveys were made in areas where the existence of cupriferous mineralizations were known; the results are given in the following notes:

In the Barrigão zone, covering three old mine properties, an E.M. survey was made over an area of 12 km2 with 12,568 points; in the zone of the mine Barranco do Vale Cova - Herdade dos Zefetos an area of 3,6 km2 with 8,422 observation points was surveyed; in the areas of the mines Ventosa - Ferraria, Moinho da Romba and Corrego da Vinha 1.5 km2, 1.8 km2 and 1.8 km2 were surveyed with the observations of respectively 1,464, 1,757 and 1,825 observation points. Some small anomalies were found and some of them shall be submitted to future study.

c) - Zone of Montemor-o-Novo.

An E.M. survey made in an area of 12.5 km2 covering the copper mines of Caeira, Cufenos, Courelinha, Carapinha and Grou with 18,685 observation points.

In the zone of the Caeira mine small anomalies were found over a pyrite dyke, known for a length of 110 m, down to the depth of 50 m and with width of 3 m. E.M. indications followed approximatly the direction of the stratification exactly in alignment with the known dyke to both sides of the known zone.

An area of 27.7 km2 with 33,796 observation points was surveyed covering the copper mines of Caeirinha, Herdade do Paço and Herdade do Corte Pereiro. Among the anomalies found a series of anomalies of medium intensity are to be noted coinciding perfectly with the old mine workings alignment.

Other E.M. surveys were made using the Turam in small zones over ore deposits of copper, galena, barytes, arsenopyrite and antimonite.

The surveys for copper ores covered a total area of 15.5 km2 with 19,166 observation points. Only in one of the areas were anomalies obtained over quartz dykes, one of them with traces of old workings with cupriferous minerals in its tips.

Over mines of other ores the E.M. experiments covered a total area of 18.7 km2 with 29,207 observations points. Some anomalies were found over the deposits with extensions beyond the known zones. Some of these anomalies are being studied.

d) - Zone of Cercal-Odemira.

A Turam E.M. survey was made in an area of 4 km2 over dykes of the B.C.P.C. type with 8,256 observation points. A series of anomalies in the porphyry, that stands out from others found, is exactly over a recently discovered dyke. On the other hand anomalies were not found over other known sometimes relatively thick dykes.

e) - Zone of Santo Aleixo da Restauração.

In this zone an area of 9.7 km2 with 10,283 observed stations was surveyed. Some anomalies were found but they seem to have no interest.

4 - FINAL CONCLUSIONS

The problem of the discovery of orebodies in developed countries is a very com

In the case of the iron pyrites orebodies of Portugal the application of the Turam E.M. method was made in the hope of contributing to the solution of this problem and eventually obtaining some positive results. If this has been in some way achieved the matter cannot be considered completely closed. Only in one case was there complete success and that was the discovery of the Cerro do Carrasco orebody which led to the discovery of another orebody of still greater importance - the Moinho orebody.

If we take the discovered reserves into consideration the cost of the whole campaign adds very little to the cost of the tons to be mined out. Cases like this must, however, be considered an exception. We must expect the orebodies to exist at a greater depth without causing electromagnetic variations clear, strong and of easy interpretation.

Due to the many origins of the anomalies - contacts of different conductivity formations, mineral concentrations, strata of graphytic schists, zones of meteoric water-flow favoring electrolitic flow, etc, - the failures will be many though one good result may pay for years of geophysical study.

Generally it is not easy to distinguish the origin of the anomalies and so the use of different geophysical methods based on different properties must be decided upon, to raise the indeterminations. Unfortunately those properties are not exclusive to the ores. Graphytic schists are good conductors and are subject also to high spontaneous polarization; basic rocks have a comparatively high gravity and granites, metamorphic rocks and consolidated sediments from the first geological eras show frequently a high speed of seismic wave propagation. In this lies the interest of the use of different methods and if we analyse the information as a whole then we may with greater assurance recommend mine workings or drill-holes whose cost is higher than the geophysical surveys. This is why the Serviço de Fomento Mineiro has on its program the covering of anomalous areas with geochemical and gravimetric surveys.

August, 1962

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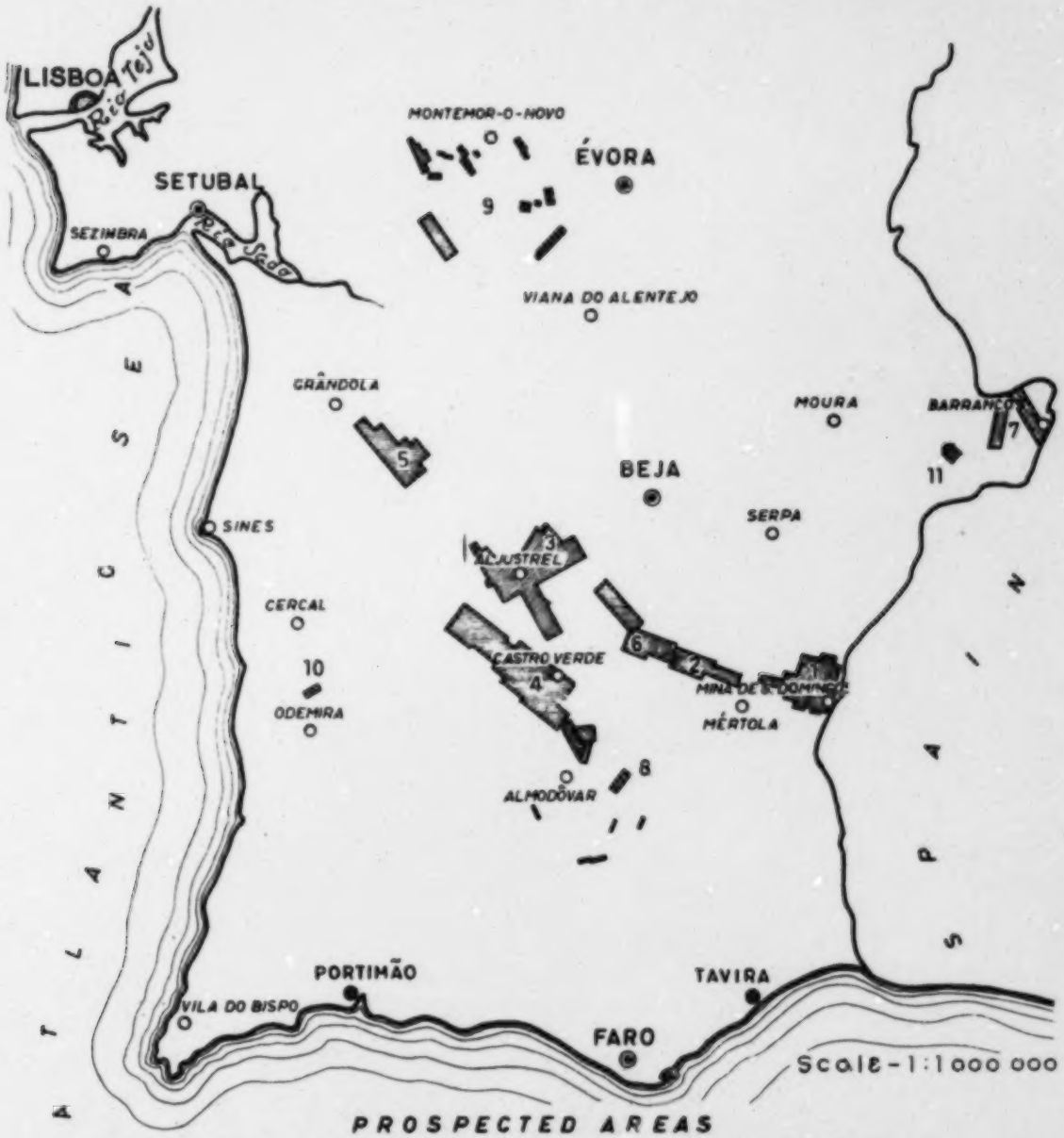
APPLICATION OF TURAM METHOD FOR PROSPECTING PYRITE AND COPPER DEPOSITS IN SOUTHERN PORTUGAL

BY

J. L. GUIMARÃES DOS SANTOS AND FERNANDO J. DA SILVA



PROSPECTED AREAS

1 – MINA DE S. DOMINGOS
2 – ALCARIA RUIVA
3 – ALJUSTREL
4 – CASTRO VERDE
5 – CAVEIRA-LOUZAL
6 – ALBERNOA
7 – BARRANCOS
8 – ALMODÔVAR
9 – MONTEMOR-O-NOVO
10 – CERCAL-ODEMIRA
11 – S.TO ALEIXO DA RESTAURAÇÃO

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FOR THE BENEFIT OF THE LESS DEVELOPED AREAS

Agenda Item: A.5.2.1

United Arab Republic

EXPLORATION FOR MINERAL DEPOSITS IN THE UAR

By E.M. EL SHAZLY, Ph.D., D.I.C.
Geological Survey
and Mineral Research Department,
Cairo

Papers have been contributed to the United Nations Conference on the Application of Science and Technology for the Benefit of the Less Developed Areas as working papers for that Conference. They are published as presented by the contributors, and the contents and the views expressed are those of the contributors. (See notes overleaf.)

NOTES

1. Papers selected for inclusion in General Sessions will be available at the Conference in the following official languages of the United Nations: English, French, Russian and Spanish.

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EXPLORATION FOR MINERAL DEPOSITS IN THE UAR

E.M. El Shazly, Ph.D., D.I.C.
Geological Survey and Mineral Research Department, Cairo

Application of Modern Criteria of Geological Exploration

1. Geological methods have been the earliest and most commonly utilised so far in mineral exploration in the UAR. Prototypes to some present-day geological methods have been used in Ancient Egypt, however, the Nineteenth Century marks the application of scientific geological exploration and mapping. At present modern criteria of geological exploration are taken into consideration, they imply using different geological guides including regional, mineralogical, structural, lithological, stratigraphic and physiographic. Regional guides are particularly suited for selecting large regions favourable for mineral deposition; while the others are used mainly for detailed exploration within these favourable regions.

2. Metallogenetic provinces and epochs: Regional guides may be expressed in terms of metallogenetic provinces and epochs where the geological development of a region creates conditions favourable for mineral deposition in space and time. These are useful for the general appreciation of the potentialities of the mineral wealth in individual countries. Growth of geological knowledge, recognition of mineral types and absolute age determinations have led to the gradual establishment of some metallogenetic epochs and provinces in the UAR and to observe their relation to comparable ones in Africa, western Asia and southern Europe, such interrelations are briefly summarised as follows:

(a) Metamorphosed iron ores of the Lake Superior type are the oldest known deposits in the UAR. They occur in metasediments believed to be corresponding to the Karagwe-Ankolean cycle estimated by Holmes and Cahen (1) to be 1200 - 1400 million years in age. Similar deposits occur in the Sudan, Saudi Arabia, and Central and West Africa.

(b) Chromite, ilmenite, etc. occur in ultrabasic and basic rocks associated with the metasediments in the Basement of the Eastern Desert, which are also present under comparable conditions in Saudi Arabia and the Sudan.

(c) Non-ferrous sulphide deposits, auriferous veins, etc. are connected with the hydrothermal activity of the late tectonic granites in the Basement of the UAR which belong to the late Pre-Cambrian - early Palaeozoic activity so widespread in the African shield. Absolute ages of the granites and related mineralisations in Africa and Asia are ranging from 640 to 480 million years, with stages of magmatic activity embracing those of Katanga and Madagascar of the Indian Ocean tectonic cycle.

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(1) Holmes, A. and Cahen, L., African geochronology, Colonial Geology and Mineral Resources, 5, 5-38 (1955).

(d) Sedimentation produced large scale deposits of phosphates, and iron and manganese ores in the UAR especially in formations ranging in age from the Carboniferous to the Eocene (FIGURE I). The most important of these are the phosphates which form a part of a large province extending from northern Africa to western Asia.

(e) The telethermal Miocene lead-zinc deposits on the Red Sea coast in the UAR are believed to be related to the outer manifestations of the magmatism of the Alpine tectonic cycle. Typical and deeper representatives of this cycle are encountered in North Africa and southern Europe.

3. Mineralogical guides: These are represented by the notable alteration zones round the epigenetic mineral deposits, oxidised ore minerals exposed at the surface, primary minerals, and characteristic gangue minerals. In the UAR quartz has been used as a guide mineral for the true hydrothermal veins such as those carrying gold, cassiterite and wolframite as quartz gangue is almost always associated with these veins. The characteristic green and blue colours of the oxidised copper minerals notably malachite and atacamite have been utilised in the search for deposits of copper and associated minerals, most copper discoveries have been due to the application of this guide. Furthermore, the recognition of the red gossan produced by the oxidation of pyrite and marcasite associated with the telethermal lead-zinc deposits led to the discovery of Um Gheig mine by a prospector.

4. Structural guides: Shear zones, faults and fractures are some of the most clear structures controlling the localisation of epigenetic mineral deposits. It has been established that the zinc-copper-lead sulphide deposits at Samiuki, Eastern Desert are essentially localised in shear zones trending N.W. - S.E. to E. - W. in Pre-Cambrian metavolcanics (2), and this has been used as a guide for searching for similar deposits thus leading to the discovery of Abu Gurdi and other occurrences. An important guide in sedimentary formations is deposition on unconformities. A good example is illustrated by the iron ore deposits of Baharia Oasis, which were first discovered at Gebel Ghorabi and later traced in other localities (3), mainly by making use of the fact that the ores are found on the unconformity between the Cretaceous and the Eocene.

5. Lithological guides: Some mineral deposits are connected with certain host rocks, this is particularly true for deposits where magmatic segregation plays a dominant role, although lithological guides apply in certain cases to epigenetic and sedimentary deposits. In the Pre-Cambrian of the Eastern Desert chromite is found only in ultrabasic rocks, and ilmenite and ilmenite-magnetite deposits are restricted in their occurrence to altered gabbros. Search for the previously mentioned ores is only restricted to their well-defined host rocks. Furthermore, telethermal lead-zinc deposits in Miocene sediments, although they occur in several types of rocks, however, they only reach economic grade in limegrits which are constituted of a mixture of lime, sand and clay. Several examples are known in which sedimentary deposits are controlled by the lithology of the enclosing formations, among these are the metamorphosed iron ore bands occurring in association with calcareous mudstones at several localities in the basement rocks in the central Eastern Desert. (4)

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(2) El Shazly, E.M. and Afia, M.S., Geology of Samiuki deposit, Eastern Desert, Egyptian Journal of Geology, 2, 25-42 (1958).

(3) Akaad, S.E. and Zaatout, M.A., The iron ore deposits of Baharia Oasis, First Iron and Steel Conference, Cairo, 1-35 (1961).

(4) Shukri, N.M., El Shazly, E.M. and Sabet, A.H., The iron ore deposit of Umm Ghamis El Zarqa, Eastern Desert, Egyptian Journal Geology, 3, 125-146 (1959).

6. Stratigraphic guides: These are particularly remarkable for following large scale sedimentary deposits occurring in certain well-defined stratigraphic horizons. The best example in the UAR is illustrated by the phosphates which occur in the Maestrichtian-Campanian, and their presence was anticipated and discovered in widely separated areas by the application of their stratigraphic guide. This also applies, but to a lesser extent, to the Senonian oolitic iron ores in the Nubian Series to the east of Aswan, and the manganese-iron deposits localised in the Carboniferous sediments in Sinai which have been recently recorded in the Carboniferous rocks of Wadi Araba on the western side of the Gulf of Suez (A.M. Abdulla, personal communication).

7. Advantages and limitations of geological exploration: As a general rule it has been found out by experience that geological guides and study of the geology of explored areas are essential for scientific prospecting, this is especially true for arid regions where rock exposures are common. In some cases geological methods give enough data, however, in others they have to be supplemented by geophysical, geochemical, exploratory mining or drilling. Disadvantages of the sole application of geological methods include cases where considerable areas are sometimes covered with windblown sand and alluvial deposits, or the outcropping part of a mineral deposit may be too small to give a reasonable idea about its potentialities, apart from the fact that it is easier sometimes to detect mineral deposits by a distinct physical property such as radioactivity rather than by applying geological guides.

Aerial Photographs and their Application for Exploration

8. Aerial photographs and geological mapping: Most of the territory of the UAR is at present covered by vertical aerial photographs on a scale ranging from 1 : 20,000 to 1 : 60,000 with the exception of some areas in the southern Western Desert. The advantages of using these aerial photographs in geological mapping and mineral exploration have been appreciated in a short time, and they have been utilised for this purpose except in some cases where detailed mapping and investigations are needed. It is generally established that geological maps are of fundamental importance to mineral exploration, and the use of aerial photographs in preparing geological and topographical maps in a much shorter time and with about one third of the expenses of the classical methods is a considerable contribution to the progress of mineral exploration.

9. Aerial photographs and geological exploration: In some cases it has been possible to observe directly a mineral deposit or its debris and to follow its extension on the photographs. This is exemplified by the iron ore deposits of Baharia Oasis in the Western Desert where the debris of the ore are considerably darker in tone than the associated sediments. However, in most cases, mineral exploration is carried out indirectly through the recognition of the characteristic geological guides on the aerial photographs. Of these, regional guides may be broadly applied by examining photographs of the suitable region in the office and choosing the areas where geological conditions are most favourable for mineral deposition, and accordingly to direct the activities of the exploration parties to these areas.

10. Shear zones as notable structural guides and talcose alteration products have been observed in the aerial photographs of Samiuki mine (FIGURE II), the extension of this polymetallic mineralisation and the location of other shear zones in the Pre-Cambrian metavolcanics have been partly carried out by the examination of the photographs of the surrounding areas.

11. Lithologic guides are expressed on the aerial photographs when the favourable host rock may be differentiated from the associated formations. The host rocks

for the ilmenite and ilmenite-magnetite deposits of Abu Ghalqa and Abu Dahr respectively, namely the Pre-Cambrian altered gabbros are readily recognised from the surrounding metavolcanics and granites, and the possibilities of the lateral distribution of the ore bodies have been determined accordingly.

12. Stratigraphic horizons connected with certain stratified mineral deposits are sometimes clearly distinguished from the associated horizons, and this has been utilised to follow the extension of the deposits in question by examining the photographs of the favourable areas and localising their particular stratigraphic guide. In Maghara area, northern Sinai, coal-bearing bands are intercalated with a flinty limestone series at the base of the Bathonian, the latter series is characterised by its dark tone in comparison with the associated Bathonian limestone-shale intercalations and the underlying light grey Bajocian limestone (M.B. Morcos, personal communication).

13. Physiography has been found to be useful as a guide in the search for the metamorphosed banded iron ores in the Eastern Desert, although it does not itself indicate the presence of these bands. Conspicuous ridges are visible on the aerial photograph of Um Nar deposit (FIGURE III), which are caused by the differential weathering of the hard iron ore bands and the softer metasediments.

14. Aerial photographs and geophysical and geochemical exploration: Geophysical flight lines, ground geophysical traverses and profiles, geochemical traverses and profiles, and delineation of areas for biogeochemical prospecting are planned and carried out directly on aerial photographs and mosaics especially in areas where appropriate maps are not available.

15. Advantages and limitations of aerial photographs in exploration: As a general rule it has been found out by experience that aerial photographs are helpful in mineral exploration especially in general planning, preparation of necessary geological maps and recognition of the obvious mineral guides. Occasionally, but not very often the photographs gave a direct clue to a mineral deposit. In detailed work additional close geological examination and mapping by classical methods are of considerable significance. In areas where outcrops are common aerial photographs are particularly useful and these are of wide distribution in the UAR, however, some parts of the Western Desert are covered with great sand dunes and the valleys are normally covered with alluvium in which cases the application of aerial photographs in exploration becomes very limited.

Geophysical Methods and their Use in Mineral Exploration

16. These methods essentially make use of notable differences in some physical properties between mineral deposits and associated rocks, or between different formations where structural information is needed. Among the geophysical methods recently applied for mineral exploration in the UAR are included the magnetic, radiometric and electrical.

17. Magnetic methods: Aeromagnetic surveys have been carried out in these areas, namely northern Egypt, southern Western Desert and central Eastern Desert. The last area has been particularly chosen for mineral exploration with special emphasis on the metamorphosed iron ores which are already outcropping at thirteen localities. Prospection is carried out by AM 13 magnetometer mounted on AN 2 planes which fly at an altitude of 200 mrs. from the ground at a speed of 180 Km/hour. The spacing between successive flight lines is 1 Km., and the direction of the lines is ENE - WSW which is perpendicular to the main structures of the Basement and the sedimentary cover. Graphs and isoline maps of magnetic field

are finally prepared on a scale of 1 : 100,000 (5). The results of the survey have been useful in locating the extension of some metamorphosed iron ores, elucidating the major structures in the area, and in mapping rocks with notable magnetism such as basalts hidden under sediments.

18. Moreover, ground magnetic surveys have been applied in several mineralised areas and positive results obtained for the metamorphosed iron ores and ilmenite-magnetite deposits. Magnetite-hematite iron ore bands have been located under an overburden of alluvium in several localities in the Eastern Desert including Dabbah, Karim, Um Ghamis and Gebel El Hadid by means of geomagnetic measurements, with Askania field balances. At Abu Dahr several ilmenite-magnetite bodies have been discovered in gabbro, and their extension under the valley alluvium and in depth verified by a magnetic survey using M 2 magnetometer (6). In common with previous Canadian experience the ilmenite ore of Abu Ghalqa which contain hematite exsolutions, gave negative anomalies in comparison to the positive anomalies exhibited by the magnetite-bearing gabbro, which constitutes the host rock.

19. In exploration for copper deposits in the Basement magnetic methods gave positive results when the mineralised shear zones and adjacent country rocks contain magnetite which is usually more abundant in the shear zones. However, in many cases both are free from magnetite and these methods are not applicable. Furthermore, the sedimentary and replacement iron and manganese ores in the sedimentary formations did not respond to magnetic exploration methods as the deposits and associated rocks do not contain magnetic minerals.

20. Radiometric methods: Regional surveys and reconnaissance have been carried out by aerial and carborne radiometric methods, and in such cases radiometric traverses, profiles and maps are plotted on a scale of 1 : 100,000. In aerial radiometric surveys airborne gamma radiation detectors PBC 1 mounted on Beachcraft or AN 2 planes have been used. Flight is normally kept at about 50 mrs. above the ground, spacing between successive lines being 1 Km. and their direction is kept perpendicular to the main structures of the investigated areas.

21. Carborne scintillation surveys have been successful in regional and semi-detailed exploration for radioactive deposits, the resulting anomalies in this case could be examined and verified on the spot. The efficiency of carborne methods depends to a great extent on the topography of the examined area and the passability of its valleys. The average density of profiles in an area of moderate topography in the Eastern Desert (7) is calculated to be 0.735 Km/Km.^{2} which is rather small, and in addition this density is not equally distributed within the same area. However, it has been possible to discover uraniferous deposits by regional carborne prospecting and to follow these occurrences by analogy with comparable geological formations and semidetailed carborne and foot prospecting, and finally by detailed radiometric foot prospecting and geological mapping.

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(5) Fahim, M., Project of work for aerogeophysical exploration in the Eastern Desert, 1961-1962, Unpublished report, Geological Survey and Mineral Research Department (1961).

(6) Garkov, Report on the geophysical work in Abu Dahr area, Unpublished report, Geological Survey and Mineral Research Department (1960).

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Geochemical Methods in Mineral Exploration

22. Geochemical methods imply the analysis of soils, waters and vegetation, and the application of the resulting chemical anomalies to trace mineral deposits. These methods have been applied in the UAR during the last three years especially in known areas with lead, zinc, copper and nickel mineralisations. Normally closely spaced grid system is used and point samples are taken from the friable superficial deposits to a depth of about 20 cms., quartered and sieved to take the fine fraction and subjected to semi-quantitative spectrographic analysis. Finally the chemical values are put on maps and plotted as lines of equal concentration of the elements sought for. In the area of Zug El Bohar high values of lead and zinc have been encountered for a distance of 50-100 mrs. from the known lead mines (8). Geochemical anomalies have been located in the vicinity but not yet checked to prove or disprove them. So far, some difficulties in applying geochemical exploration are encountered due to the fact that fine eluvium is not so common, and water points and plants are scarce under desert conditions.

Drilling and Exploratory Mining

23. These methods are necessary to obtain precise information on the extension of mineral deposits laterally and in depth, and the tonnage and grade of the ore under exploration. For deposits exposed at or near the surface trenches and pits are made and are found to be in several cases more useful than drilling. In addition, it has been found out that mining is more convenient than drilling where topographical conditions are not convenient for the latter, recovery by drilling is low, and when large technological samples are required. Otherwise drilling is normally used especially in cases where attaining considerable depths is needed and exploration mining will become expensive. Percussion drilling has been successful in comparison to rotary drilling in the friable Miocene lead-zinc deposits and in Baharia iron ores which may be earthy or cavernous. However, rotary drilling is recommended in most cases as it is versatile and quick especially in hard formations, and where greater depth or inclined holes are required.

Coordination in Mineral Exploration

24. By the advance of exploration and the diversity of the methods applied two factors become important, namely, the choice of the most suitable methods for each particular mineral deposit and coordination of the activities related to this problem to achieve the best and most economic results. In common with other countries, our experience points out that regional geological maps compiled with the help of aerial photographs combined with aeromagnetic surveys provide the basis for scientific exploration. In arid regions due to the common occurrence of good exposures geological guides and surface geological investigations should be fully exploited. The knowledge of the types of deposits sought for helps by comparison to choose the most suitable geophysical and geochemical methods especially in the use of magnetic and radiometric methods in the search for magnetic and radioactive minerals respectively. In other cases complex surveys may have to be conducted and the best methods found out empirically. Complex geophysical and geochemical surveys have been carried out at typical mineralised areas in the UAR to test the most suitable and cheapest exploration methods for further application in comparable areas. Coordination of the activities of the various organisations engaged in mineral exploration and related problems including those of petroleum and ground water are significant for the compilation of data,

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exchange of experience, division of labour, etc. This is carried out on the scientific level through the Science Council and on the industrial level through the Organisation for the Execution of the Five Years Industrial Plan, or by direct contact between the organisations concerned.

Suggestions for the Development of Mineral Exploration

25. It is most important for developing countries to achieve a sound mineral economy which could only be realised through a vigorous and organised programme for mineral exploration whose immediate fruits may not be startling but its solid results will unfold themselves within perceptible time. It is believed that the following suggestions will be of some help to developing countries in this respect:

(a) To establish national geological services if they are not in existence and to strengthen the existing ones. These services should be at least responsible for the fundamental basis of mineral exploration, their share in other activities will depend on the circumstances of each country.

(b) To coordinate the activities of the organisations dealing with mineral exploration and related matters through planning bodies on the scientific and industrial levels.

(c) To develop efficient means of publication and exchange of ideas especially between countries lying in the same comparable geological, geographical and physiographic regions. This will help to assess their mineral potentialities and to choose the most suitable guides and exploration methods by correlation.

List of Figures

FIGURE I. Map of the UAR showing general distribution of areas of mineral deposition.

FIGURE II. Shearing at Samiuki mine area, Eastern Desert.

FIGURE III. Conspicuous ridges at Um Nar iron ore deposit, Eastern Desert.

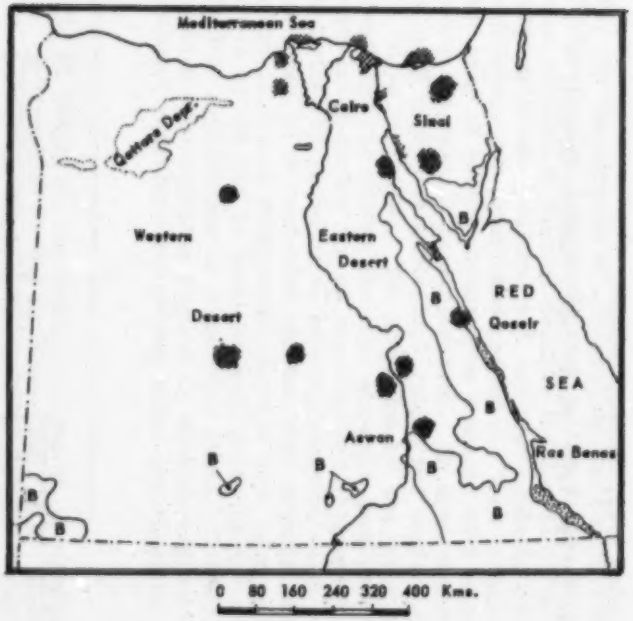

FIGURE 1
Map of the U.A.R. showing general distribution of areas of mineral deposition.

Sedimentary cover

Basement, Areas of Pre-Cambrian to Palaeozoic mineral deposition

Areas of Quaternary mineral deposition

Areas of Miocene mineral deposition

Areas of sedimentary Carboniferous to Eocene and probably Oligocene deposits

FIGURE II. Shearing at Samiuki mine area, Eastern Desert.

FIGURE III.
Conspicuous ridges at Um Nar iron ore deposit Eastern Desert.

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Agenda Item: A.3.4.2

Israel

DEMINERALIZATION OF SEA WATER FOR PRACTICAL APPLICATIONS

By J. ADARI,
Managing Director,
Desalination Plants, Ltd.

Papers have been contributed to the United Nations Conference on the Application of Science and Technology for the Benefit of the Less Developed Areas as working papers for that Conference. They are published as presented by the contributors, and the contents and the views expressed are those of the contributors. (See notes overleaf.)

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DEMINERALIZATION OF SEA WATER

FOR

PRACTICAL APPLICATIONS

By J. ADARI,
Managing Director,
DESALINATION PLANTS LTD.

* * * * *

Water, many will readily agree, is the key to the economic development of vast areas in many parts of the world. The geographical distribution of fresh water sources is uneven and does not always correspond to requirements. The only source of water that is practically unlimited is the sea. The conversion of sea water into fresh water, however, is often raising objections which derive their momentum from unfavourable cost factors. Let us therefore start our discussion with a brief analysis of natural and desalted water cost factors.

1. COST FACTORS OF NATURAL WATER SUPPLY

Water supply facilities must always be designed to meet increasing demand for agricultural, industrial and domestic uses. The growth of the national economy together with the improvements in the standards of living are coupled with swift increases in the demand for water. Supply facilities, therefore, must be planned with considerable excess capacity, which calls for large capital investments.

This problem is universal. Water projects must always be planned with excess capacity, leaving the unutilized capital idle for long periods. It is true, of course, that the idle capital could easily be written off with the rest of the investment by charging it against water actually supplied. Such a method of calculation tends to increase the price of water significantly. The economic cost of idle capital, however, is much higher than dollars and cents of expenditure would indicate. Idle capital could be brought to productive use and it is the benefits of such productivity that must be charged against the cost of water. The greater the marginal efficiency of capital the higher the cost of idle capacity in water installations.

When we measure the total capital investment against the quantity of water produced over a certain period we may find that unless depreciation charges are stretched over many decades the cost is high. By allowing capital expenses to be repaid over a long period we admit economic forces that tend to cut deeply into the ratio of water charges to the real value of the investment. Inflation and rising prices tend to multiply the amount of capital required to rebuild existing facilities while the depreciation charges are usually compiled on the basis of historical costs. If a larger part of the investment is to be retired in real terms costs components representing capital outlays will have to be changed considerably with a significant increase in the price of water.

Ambitious water projects take many years to complete, they may demand a large number of employees and require large amounts of capital. In short, considerable economic resources must be mobilized with their benefits many years away. Such a drain on economic resources may have significant long-run effects on the national economy and must be evaluated accordingly.

An analysis of natural water costs will reveal two things:

(a) There is a built-in tendency of water supply costs to increase.

(b) There is a large and increasing discrepancy between prevailing and real economic costs of water supply.

The result - increasing hidden national subsidies to the cost of water.

2. COST ELEMENTS OF DESALTED WATER

The main cost elements of demineralized water are very much the same as those of natural water. Capital charges, power and wages comprise the most important cost components of such water. There are, however, three important considerations that tend to distinguish between the cost structure of demineralized water as compared with natural water.

(a) The payback period of the investment is relatively short and the chances of getting back in interest and depreciation the real value of the invested capital are much better in saline water conversion installations than in large natural water supply projects.

Technological improvements, too, may cut deeply into the anticipated economy of long-range projects. The same is true for geographical changes in the distribution of national production facilities. All these considerations put a heavy toll on long-range projects. By restoring to projects of a shorter retirement age, savings are realized that may offset the additional expenses involved.

(b) Increasing the supply of desalinated water to meet a growing demand tends to decrease the cost of water without adversely affecting the sources of supply.

The ever-increasing demand for saline water conversion equipment and the keen interest among manufacturers in various demineralization processes have already pushed desalination costs considerably downward. The costs of converting sea water were reduced from over $5.- per 1,000 gallons to about $1.- in one decade. The intensity and variety of research and development programs recently undertaken give every indication of further improvements. Consequently, many parts of the world face a situation in which ever-increasing costs of natural water rise to meet the decreasing costs of converted sea water. Finding the points at which these two costs equal each other should be an important objective of every nation concerned with water problems.

(c) Saline water conversion installations hardly affect general economic conditions. Their size and structure leave little difference between such plants and automated industrial establishments of similar dimensions. Moreover, since conversion equipment does not necessarily have to be built at the location of the installation, the impact of large capital investments on the economy can easily be adjusted to suit local conditions.

To the general evaluation of cost trends affecting natural and demineralized water, a number of considerations must be added that have a specific bearing on less developed areas.

Water supply systems in modern countries were developed over many years, sometimes spreading the cost of such installations over several generations. Such a gradual development of water installations required a method of costing that less developed countries can hardly reckon with. Suppose location A is situated 1,000 miles from the closest source of natural water but a pipeline previously installed brings water in large quantities to location B, 50 miles away from A. The cost of supplying water to location A would be equal to the cost of transporting the water over 50 miles rather than 1,000 miles. This kind of marginal costing can be applied only in areas where existing water facilities are extensive enough and independent enough to make it possible. Newly-developed areas are usually less fortunate. In such places the full cost of water must be applied, and this tends to increase considerably the price of water to consumers.

In newly-developed areas the development of adequate water supply systems is usually integrated into a general plan of economic development. As such the water supply system must be geared to the patterns of economic development in each area. It would not be sensible to develop a water system suitable for an intensive agricultural economy if the area involved is planned for industrialization and urban development. Many manufacturing industries and urban communities can develop on water supplied at prices that would push farm products' costs to uncompetitively high levels. It is unnecessary to make high capital investments that would result in very low water unit costs when smaller investments resulting in higher unit costs would be adequate. The capital saved could effectively be utilized for other purposes yielding higher interest rates carrying larger depreciation charges.

Lack of capital is usually one of the most important factors limiting the pace of economic growth in less-developed areas. A careful evaluation of the real water requirements in each area with special consideration of the permitted water prices can help save and generate large amounts of capital that would otherwise be invested in ambitious uneconomical water projects aiming at unrealistically low prices. Such an evaluation will often point at the economy of local, small-scale solutions with short retirement age rather than nation-wide extensive long-range projects. Among such solutions the demineralization of saline water will play an ever-increasing role.

Conversion installations for sea and brackish water are operating in many areas. Detailed literature is available describing the various processes and techniques and little can be added here.

A relatively new approach was adopted in the development of the freezing process. The idea is to design and build a complete self-contained unit in the factory, capable of operating at a certain capacity. A conversion plant will consist of one or several such units linked together in a battery. The advantages foreseen in this approach are:

(a) The module is engineered once and can be used for plants of different size with no additional engineering.

(b) The module serving various-sized plants can be produced in large series thus reducing the production cost considerably.

(c) The erection of a plant consisting of self-contained and complete units is simple and demands minimum time. The workers doing the erection job on site do not have to be highly skilled.

(d) By having several modules in one plant stand-by units are not necessary. Maintenance time is cut and can be extended over a longer period on a rotational basis.

(e) The investment in the plant is proportional to needs and the whole invested capital is utilized in full from the very beginning. The plant can be increased with time according to growing needs and no big reserves are needed.

(f) Desalination equipment is undergoing development and modifications continually and the cost of the equipment is decreasing while efficiency is increased. The ability to aid units to an existing plant enables the user to increase production by adding more developed units and thus reducing the water cost without having to leave a complete plant in abeyance.

(g) Areas where moderate plants are suitable in many cases lack refrigeration facilities and ice supply. A combination of a freezing conversion plant to produce fresh water and ice is of advantage and may reduce water cost.

It is beyond the scope of this article to enter into detailed calculations of investment and water cost for various combinations of plants according to this approach. A fair idea of equipment cost, power requirement and manpower for operation is given in the following chart.

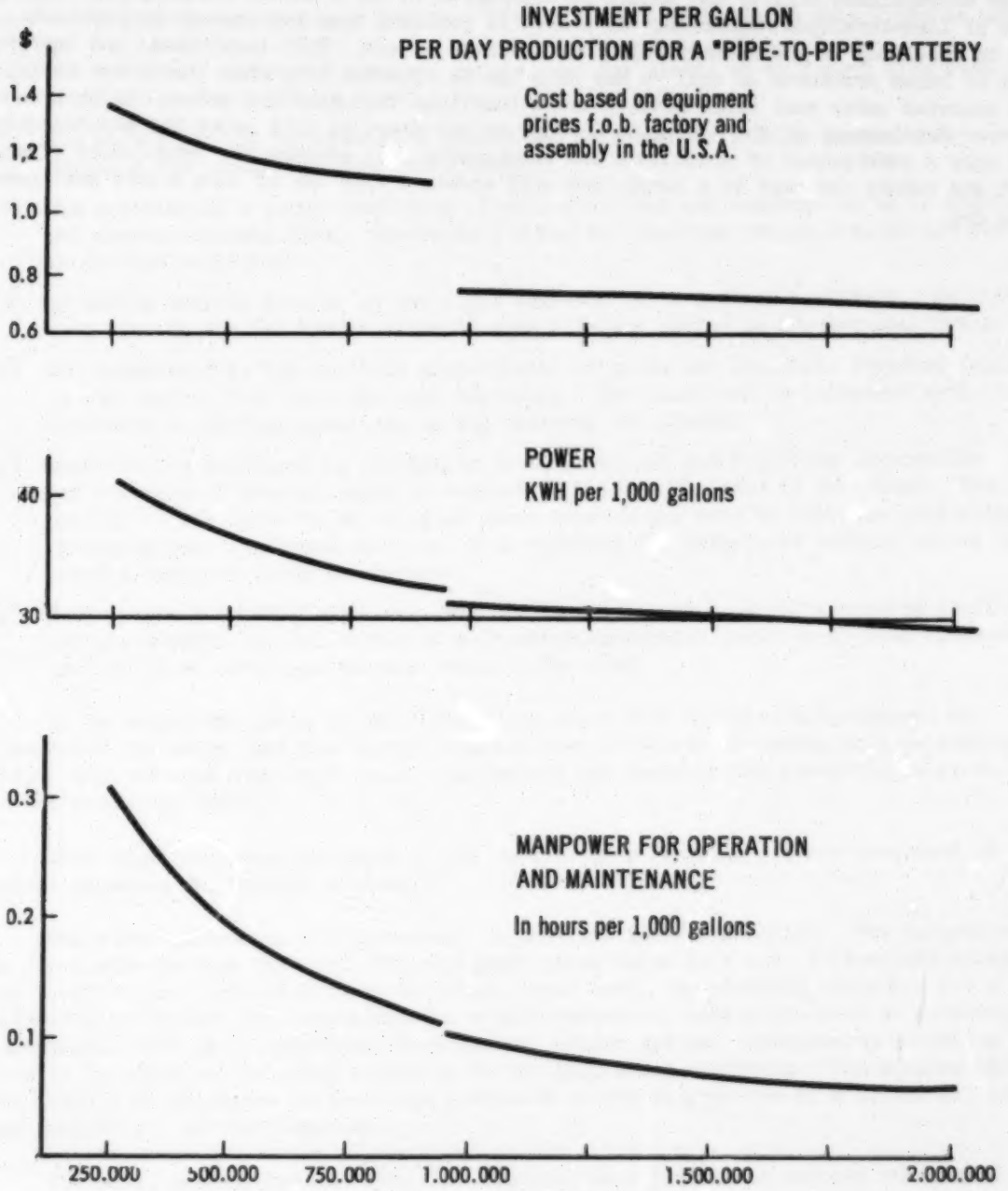
This chart was computed based on the results of a freezing process developed in Israel known as the Zarchin process.

The curve indicating the investment is in $ per installed gallon. The investment is for a pipe-to-pipe battery. The equipment price taken is f.o.b. factory and assembly and erection are calculated based on U.S.A. labor cost. By plotting the curve for a pipe-to-pipe battery the investment for a self-contained conversion unit is attained independent from site conditions, location and intake system. Investments depending on site location can be added according to the individual condition. The modules used for investment estimates in the range indicated in the diagram are of a 60,000 gl. per day and 240,000 gl. per day capacity.

The power consumption and operation expenses were plotted in kwH and man-hours per 1,000 gl. so that local costs and wages can be applied.

The curves indicate the conditions today. Research and development are continued and improvements are anticipated. A demonstration plant is being built in Eilat on the gulf of Akaba based on the Zarchin freezing process and on the module approach described.

There are different processes and different approaches to solving the problem of conversion of sea water into fresh useable water. This field is so wide and important that it arouses the imagination and curiosity of many interested scientists. At the state of art today there is no process or approach that can claim full superiority. Development work continues and increases. One fact is unquestionable. The conversion of sea water is an accomplished reality and should be considered in the economic planning and development of less-developed countries. It should be realized that any process or approach can be developed in the factory only to a definite extent. Full development and improvement of known processes as well as new ones can be achieved only when plants are installed and operated under real field conditions in locations that need the water. In this sense further development of the equipment depends on the users as well as on the manufacturers and only a combination of production and utilization will advance the improvement of equipment and reduce the cost to a level that will enable a wide use of this source that never runs dry.



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ON THE APPLICATION OF SCIENCE AND TECHNOLOGY
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United Kingdom

SELECTING A MINERAL CONCENTRATION PROCESS

By M.C. FLEMING, B.Sc., Ph.D.
Professor of Mineral Technology,
Toyal School of Mines

Papers have been contributed to the United Nations Conference on the Application of Science and Technology for the Benefit of the Less Developed Areas as working papers for that Conference. They are published as presented by the contributors, and the contents and the views expressed are those of the contributors. (See notes overleaf.)

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SELECTING A MINERAL CONCENTRATION PROCESS

by M.G. FLEMING, B.Sc., Ph.D.
Professor of Mineral Technology, Royal School of Mines.

INTRODUCTION

1. Only rarely do mineral deposits exist in sufficient purity to allow them to be mined and supplied directly to the primary consumer. In all but exceptional cases, the ore must first be concentrated to separate the valuable minerals from the worthless rock. Mineral processing, therefore, is an essential part of the development of natural mineral resources; whether in the production of suitable raw materials for home industries like fertilizers, cement and glass manufacture or in the preparation of marketable products for export such as metallic mineral concentrates. Mineral technology has expanded rapidly to meet increasing demands for mineral products and a wide variety of treatment methods is available.

2. However, there is no simple formula for selecting a concentration process. The size, grade and mineralogical composition of the ore body; technical considerations of mining and mineral processing; accessibility; markets and the availability of capital are inter-related factors which must all be considered before a decision is reached. The selection is further complicated by the fact that more than one technical solution is usually possible and estimation of the economic factors involves long-term predictions with a wide margin for error.

3. This paper attempts a broad outline of the limitations and potentialities of modern mineral processing techniques. It is hoped that it will assist government officials responsible for development of their countries' mineral resources to view the various aspects of these problems in perspective.

TECHNICAL CONSIDERATIONS

4. The earth's crust is composed of some 3,500 mineral species, each identifiable by its basic crystal structure and other physical and chemical properties. Only 300-400 are common or important constituents of ore deposits and a typical ore may contain 10-20 of these. The proportion of valuable mineral present determines the grade or richness of the ore, but the kind and proportion of the other mineral components - the gangue - are equally important in determining the mode of separation that may be employed. The possible combinations are, thus, enormous and, while they may have similarities, no two ores are identical. Furthermore, the geological origins or genesis of mineral deposits result in variation in composition and the relative proportions of mineral constituents within a single ore body. This infinite variety makes every mineral processing problem unique and distinguishes the concentration of ores from other industrial operations.

5. Since most ores are mined or quarried from solid rock with their mineral constituents firmly locked together, the first step in any concentration process is to liberate the valuable mineral grains from the matrix or gangue with which they occur. This is done by crushing or grinding in stages until the entire mass of the ore is so fine that the valuable mineral exists essentially as separate and discrete grains, uncontaminated by adhering gangue. With rich, coarsely-crystalline ores an effective degree of liberation may be achieved at lump sizes. With fine-grained, intimately intergrown ores this may involve grinding to a maximum particle size of less than 0.05 millimetres, or about two-thousandths of an inch. Even when the ore deposit is a soil or sand or loosely-compacted rock, some form of grinding is usually required to break up aggregates and to remove coatings from the mineral surfaces which would otherwise complicate the subsequent concentration process by masking their specific properties.

6. All mineral processing is based on the exploitation of differences in the properties of the mineral constituents. For example, a typical tin-tungsten ore may contain cassiterite (tin oxide), wolframite (iron-manganese tungstate), quartz and half a dozen other silicates. The gangue minerals are relatively light and the property of specific gravity may be exploited to remove them from cassiterite and wolframite. However, the distinction between the two valuable minerals with regard to this property is insufficient to permit them to be separated by gravity methods and some other treatment is required. Usually, wolframite is magnetic and cassiterite is not; so that magnetic separation may be employed for the final stage. Occasionally, however, the cassiterite associated with a particular ore deposit contains minute quantities of iron and its magnetic susceptibility overlaps that of wolframite; in such cases another method, based on a different property, must be sought. This inconstancy in a mineral species is a further complication familiar to mineral processing engineers.

7. In addition to specific gravity and magnetic susceptibility, physical properties forming the basis of mineral separation techniques include: colour, lustre, hardness, shape, electrical conductivity, fluorescence and radio-activity. The chemical properties of minerals are even more diverse than their physical properties and leaching with selective solvents, which will dissolve the valuable minerals while leaving the gangue minerals unaffected, is a method of chemical processing commonly used for the recovery of gold and uranium and, increasingly, for the recovery of other metals from complex ores. Gas-solid reactions at moderately high temperatures provide another from of chemical treatment frequently used as a stage in mineral processing operations. The physico-chemical properties of mineral surfaces provide the basis for the most important of all concentration techniques - the froth flotation process.

8. Figures I and II illustrate some of the methods used commercially to separate minerals according to their different properties. With simple ores, a single technique will often provide a suitable concentration. With complex ores, these and other techniques must be linked together to separate first one group of constituents and then another until the impurities are finally eliminated and only the valuable minerals remain.

9. All of these methods have their limitations. The properties of minerals which occur together in a particular type of ore deposit frequently overlap. Impurities, like the trace of iron contained in some types of cassiterite which was mentioned earlier, often interfere with a process. Chemical methods usually require the addition of at least equivalent quantities of reagents or of fuel to supply heat and their cost may exceed the value of the product. However, the most common limitation is that imposed by the size and the mass of the particles after they have been liberated. Figure III shows the size range over which a

number of well-known mineral processes are effective. In each case the efficiency falls off towards the lower end of the size scale and many of these methods are either useless or will yield low recoveries when applied to ores which require fine grinding for the liberation of their constituent minerals. On the other hand, insufficient grinding provides incomplete liberation and this, in turn, results in low-grade concentrates and poor recovery of values. Unliberated particles or middlings, consisting partly of valuable mineral and partly of gangue, have properties lying between the two and no concentration process can treat them effectively.

GEOGRAPHICAL AND ECONOMIC CONSIDERATIONS

10. In addition to the basic mineralogical and process limitations are limitations imposed by geographical and economic considerations. These include the cost and availability of water, fuel, power, reagents and other supplies, suitable labour, facilities for the disposal of waste materials, transportation and the existence of a steady and profitable market for the product. The possible influence of each of these factors is important and so varied as to be quite beyond the scope of this paper. However, a few examples may serve to illustrate their influence on the selection of a concentration process.

11. Water. In most mineral dressing operations the ore is ground in water and concentration is effected in a water suspension. The quantity required may be as much as nine tons of water for each ton of ore treated, although an appreciable proportion of this may be re-used if the circumstances warrant the additional cost of reclamation. Not only the quantity but the quality of the available water may be a decisive factor in choosing a process. Hard waters, for example, are unsuitable for use with soap or fatty acid reagents while amines, another type of collector frequently employed in flotation, are precipitated by dissolved or colloidal silica from natural waters.

12. Fuel. Dry processes, on the other hand, require the feed to be bone dry and, even in very arid regions, this may necessitate artificial drying during at least part of the year. To prepare an ore containing, say, 5% moisture for high tension electrical separation would necessitate the supply of about a gallon of fuel oil per ton to reduce it to the essential limit of 0.5% moisture.

13. Power. Crushing and grinding account for the greatest proportion of power consumed in ore treatment. The requirement may range from as little as 5 kWh/ton of ore for the concentration of a beach sand to 50 kWh/ton for the flotation concentration of a hard rock ore which is liberated only at very fine size. The cost of power is equally variable - about 0.025 sh. per kWh from a convenient hydroelectric grid in Norway but as much as 0.3 sh. per kWh from a diesel generator in Bolivia. The examples chosen thus show an extreme range of 0.1 to 15 sh. per ton of ore treated for power costs alone.

14. Reagents and other supplies. The cost of all supplies is necessarily high in inaccessible areas. Grinding balls which cost £60/ton in the U.S.A. cost £80 by the time they have been delivered to a remote plant in Peru. With sulphuric acid at £5/ton in Northern Rhodesia an acid leach process is attractive which could not be contemplated in southern Tanganyika, where the cost is £50/ton.

15. Labour. Steady, efficient production requires skilled, conscientious and experienced operators. Except on small, "shoestring" operations, however,

the lack of an industrially experienced local labour force is seldom a process limitation, for the deficiency can always be made good by intelligent training and close supervision.

16. Disposal of Waste Materials. In remote regions, the disposal of mill effluents presents no problems but, in populated, agricultural areas of central Africa or India, the control of waste and the avoidance of stream or river pollution is an important aspect of process design.

17. Transportation. The increase in cost of reagents and supplies caused by high freight charges and the consequent effect on the economics of many processes have already been mentioned. The cost of transporting mineral products to a ready market may be equally critical in determining the kind of process or the degree of concentration necessary to make an operation profitable. For instance, the mineral fluorspar is commonly marketed in two main grades - "metallurgical spar" with a specification of 87½% CaF_2 and "acid spar" with a specification of 96% CaF_2. The first sells at about £14/ton in Europe and the second at about £19/ton. The difference in these prices might easily mean the difference between a profit and a loss if the product had to bear appreciable freight charges and might well justify the additional capital cost and higher operating costs that would be required by a plant capable of producing premium grade spar.

18. Markets and Product Specifications. Second in importance only to the limitations imposed by the mineralogical nature of the ore are those imposed by buyer and consumer. All mineral products are sold to specifications which control not only the valuable mineral content but, usually, the size distribution and the proportions of certain deleterious impurities. The process must be designed to meet these specifications. Metal prices are subject to the same kind of fluctuations as agricultural products. For example, in the last twelve years the price of copper has ranged from a high of £436/ton to a low of £160/ton, lead from £180 to £ 57 and tin from £1,615 to £ 570. Non-metallics are sold, for the most part, by private contract to the buyer's specifications. It is obvious, therefore, that selection of the most suitable mineral process depends to a large extent upon marketing considerations.

ORE TESTING

19. Technical problems associated with the selection of a process are resolved by laboratory testing of representative samples of the ore. This comprises three stages: the first to determine the nature of the ore and its amenability to the various concentration techniques, the second to develop a detailed process and the third to provide engineering data for the design of the plant.

Amenability Testing

20. The first stage is diagnostic. It classifies the problem and assesses the difficulties to be overcome in its solution. It is qualitative rather than quantitative. The general mineralogy of the ore must be established and related to the methods of concentration available. Not only must the mineral constituents be identified but their crystal interlock and size characteristics must be determined. Macro- and microscopical examinations are supplemented by heavy liquid and superpanner tests on ground and sized products. Chemical tests and specialized techniques fill out the information necessary to state the problem in mineral dressing terms and to enable the most promising process or combination of processes for concentration of the valuable constituents to be tentatively selected. From his own experience and the published

experience of others, the investigator will decide on the initial conditions for batch testing of the ore by the selected process and, from this starting point, he will embark on a series of tests in which every condition and every product is closely examined at each stage of the operation. Scientific reasoning combines with experience and judgement to interpret the observations and to modify the conditions from one test to the next.

21. In general, the results of the amenability tests will place the problem in one of three categories:

I A simple straightforward ore responding to conventional methods of treatment with results similar to those obtained in well-known commercial operations and revealing no unusual or complicating features;

II An essentially simple ore which has responded reasonably well to treatment but which has exhibited some unusual characteristics that might complicate a normal operation if they proved to be persistent;

or a complex ore of a familiar type which is known to be difficult to treat and the behaviour of which can only be predicted by the detailed examination of samples representing every portion of the ore body;

III Ores for the treatment of which no established precedent exists. Unusual minerals or mineral associations which have not previously been successfully concentrated. Complex crystal intergrowths or grain coatings which make it exceptionally difficult to achieve liberation of the ore into discrete mineral particles. Partially decomposed ores and soils in which the valuable constituent may be present in a wide range of secondary minerals in varying stages of alteration.

22. Most ores will fall into the first category, but an appreciable proportion of ores belong to the second category. With these, amenability tests provide warning that an exploratory ore testing phase will be necessary before detailed testing for the development of a concentration process can begin. Such problems are often recalcitrant and the time and effort needed for their solution is not safely predictable. Ores of the third category represent a research problem that may occupy a team of experts for five years or more although, as the way is uncharted, there is no certainty of a successful solution in terms of current economics.

Process Testing

23. In this stage is included all the work necessary to solve the basic metallurgical problem revealed by amenability testing and subsequent exploratory work. With simple ores of the first category the inference with regard to treatment method is reasonably clear, but optimum conditions must be determined for each stage of the process and carefully related to the geographical and economic aspects of the problem.

24. With ores of the second category an additional exploratory phase is necessary and, even when this has been successfully completed, the development of a treatment method may be a long and tedious business. The processing

of complex ores frequently involves the resolution of a very large number of simultaneous variables and the amount of laboratory work required may be formidable. The final decision as to what constitute the optimum conditions requires the careful assessment of test data from which grades, recoveries and costs can be weighed and compromised, and must usually be confirmed by continuous operation in a pilot plant.

25. For ores of the third category, all of these factors are accentuated by the unusually complicated nature of the problem.

Detailed Design Testing

26. Following the selection of a concentration process, a final stage of ore testing is necessary to provide full data on flow rates, volumetric capacities, circulating loads and other circuit details required for the engineering design of the plant. This work can only be commenced when the process has been fully agreed and must be carried out in close collaboration with the engineers responsible for the design and erection of the plant.

Cost of Ore Testing

27. It is quite obvious that no fixed scale of charges is possible for ore testing because the cost will vary widely according to the nature of the ore and the extent to which the investigation is pursued. Many machinery and reagent manufacturing firms maintain laboratories which undertake limited investigations free of charge or at nominal cost in the prospect of subsequent sales. Private and government research establishments usually estimate the cost of amenability tests on the basis of past experience with similar problems and, when the amenability tests have been carried out, work to an agreed budget. The following estimates, which do not include allowance for continuous pilot plant testing, may be useful as a rough guide:

Example A: A simple tin ore containing some sulphide minerals. Category I.

Estimate for amenability testing	£150
Allowance to be made for process testing	£350

Example B: A fairly complicated copper ore containing large quantities of pyrite and small quantities of lead and zinc sulphides. Category II.

Estimate for amenability testing	£200
Allowance to be made for process testing	£800

Example C: A rather complex fluorspar ore from which it is hoped to produce acid grade spar by flotation. Category II.

Estimate for amenability testing	£250
Allowance to be made for process testing	£1,250

Ore Testing in Less Developed Countries

28. In the past thirty years the empirical art of ore dressing has become a complex technology and "trial-and-error" methods of testing have given way to the systematic organization of industrial research. A fully equipped, modern laboratory represents a very large investment that could only be justified and supported in a country with an important and flourishing mining industry. These facilities already exist in many countries and, through technical aid schemes, the impartial assistance of such establishments as the Warren Spring Laboratory of the Department of Scientific and Industrial Research may be obtained for any complex or difficult mineral processing problem.

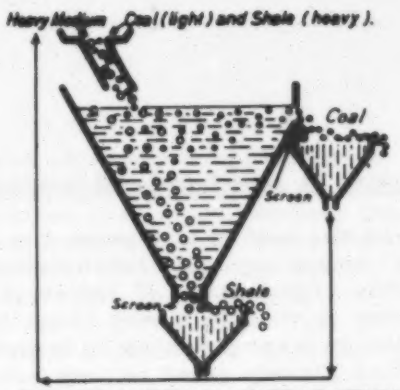
29. This is not to suggest, however, that less industrialised countries should not have their own ore testing laboratories. In the author's opinion, such facilities are an integral part of the development of mineral resources anywhere and should grow with the industry they serve. In addition to the obvious advantages of carrying out preliminary investigations with a full appreciation of local conditions, these laboratories complement the work of geological surveys, disseminate technical information and do much to improve the practice of small mineral processing operations. Much useful work can be done and much experience can be gained in a modestly-equipped, inexpensive laboratory as long as its essential limitations are appreciated and it is free to call on the highly specialized services of a large, experienced research establishment.

CO-ORDINATION AND TIMING

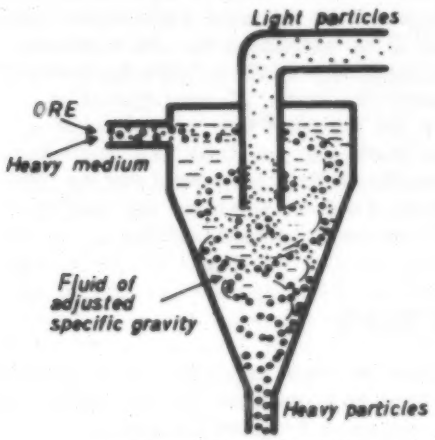
30. Amenability testing should be undertaken as soon as sufficient geological evidence has been obtained to justify a detailed exploration of the discovery and as soon as the deposit has been sufficiently exposed to provide samples indicative of its general mineralization. The stage described as process testing would not ordinarily be justified until it was clear that the ore body was of sufficient size and value to make its exploitation economically attractive. Furthermore, unless there was material available that was similar in grade, mineral distribution and grain size to that which the plant, when built, would have to treat, much of the work would have to be repeated when the true character of the ore body became apparent. The importance of having samples for testing which are representative of the ore which will have to be treated cannot be over-emphasized. The point is so elementary as to seem inescapable and yet, time and again, expensive and painstaking investigations are carried out on samples which prove to be quite different in certain essential characteristics from the material which will make up the plant feed.

31. Mining exploration to establish the ore reserves, process testing, market surveys and the assessment of power, water and other supplies are all essential factors in the development of a mineral deposit. Their interdependence necessitates the closest co-ordination at every stage. The selected concentration process must be suitable for the particular ore body which it is designed to treat, it must operate efficiently under the restrictions imposed by its location and its products must be marketable at a profit.

Most metallic minerals have a higher specific gravity than the gangue minerals with which they are associated. For ores that liberate at coarse sizes, this simple method works well and millions of tons of metallics, non-metallics and coal are treated daily by the dense medium separation process. The vessel is filled with a heavy liquid or, more frequently, a suspension of finely ground heavy solids which acts as a fluid medium of adjustable density. "Floats" flow over the top while "sinks" are drawn out the bottom of the vessel. The products are screened to separate them from the medium which is recycled.



DENSE MEDIUM SEPARATION



HYDROCYCLONE

Small particles would settle too slowly in a bath of the type shown above, so centrifugal force is used to augment the force of gravity and speed up the separation. Feed consists of a mixture of fine ore and heavy medium and is pumped under pressure into the conical vessel. The low specific gravity minerals flow out of the top while the heavy minerals are removed from the bottom. As before, the products must be screened to separate them from the medium. Large forces can be developed and cyclones have amazing capacity for their size. Hydrocyclones, using only water as the medium, are employed to classify material into different size fractions and to remove fine slimes.

Magnetic permeability is a property that is shared in some degree by all minerals containing iron. For strongly magnetic minerals like magnetite, methods of the kind illustrated here are effective. For weakly magnetic minerals like hematite, wolframite or columbite, much more intense magnetic fields must be employed. As with most mineral processes, the products are frequently retreated in similar machines to clean the concentrates and to remove the last trace of magnetics from the tailings.

MAGNETIC SEPARATION

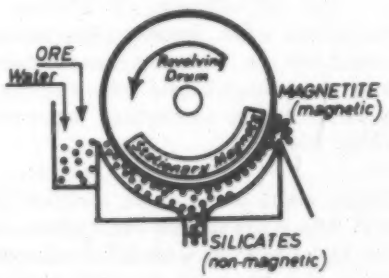
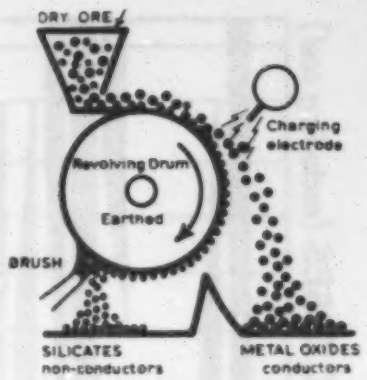


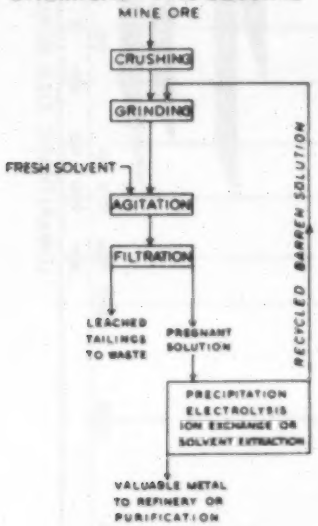
Figure I

Electrical methods of separation depend on the fact that the conductivity of minerals varies widely. Using charges of up to 50,000 volts, conductors like ilmenite or rutile may be separated from insulators like quartz or zircon. Dry ore is fed on to an earthed revolving drum. The ore particles are indiscriminately charged by the electrode but the conducting minerals quickly lose their charge to the earthed drum and are thrown off in a normal trajectory. The insulators are attracted to the drum and are removed as shown.



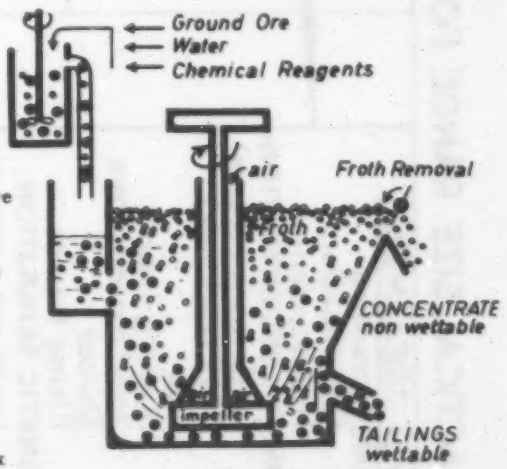
HIGH TENSION SEPARATION

CHEMICAL PROCESSING



The diagram shows a generalized flowsheet for the chemical treatment of an ore by leaching. The process depends on the existence of a cheap, selective solvent and is used to recover gold, silver, uranium, copper and other metals from complex ores. A gold ore would be crushed and ground to expose the minute particles of precious metal and then agitated for 24 hours in a pulp or slurry with a dilute solution of sodium cyanide. This selectively dissolves the gold and the pregnant solution is then filtered off, precipitated with zinc dust and the zinc-gold precipitate is melted and refined to produce bullion.

Flotation exploits differences in the surface-chemical properties of minerals. A myriad of air bubbles is blown through a water suspension of finely ground ore in which the desired minerals have been selectively waterproofed by the addition of suitable chemical reagents. The valuable particles attach to the bubbles, rise to the surface and are skimmed off as a froth, leaving the wetted gangue particles in the suspension. The development of this sensitive process has opened up thousands of ore deposits that were too low grade or too complex to be treated by other methods.



FLOTATION

Figure II

PRACTICAL SIZE RANGE FOR VARIOUS MINERAL UNIT PROCESSES (excluding coal)

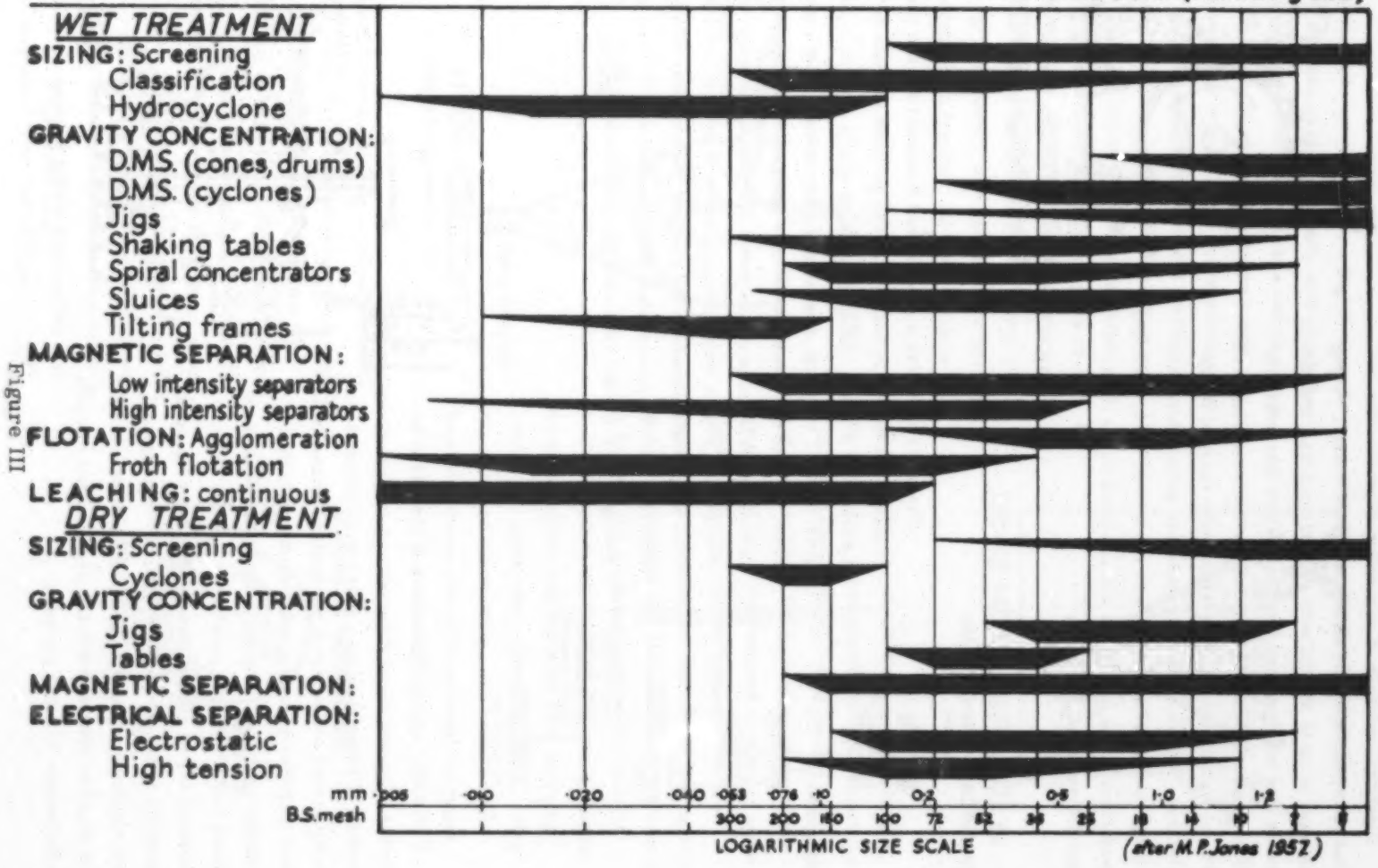


Figure III

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UNITED NATIONS CONFERENCE
ON THE APPLICATION OF SCIENCE AND TECHNOLOGY
FOR THE BENEFIT OF THE LESS DEVELOPED AREAS

Agenda Item: A.5.2.3

Nigeria

LIMITING FACTORS IN THE MECHANISATION OF MINES UNDER CONDITIONS PREVAILING IN LESS DEVELOPED AREAS

By DAVID I. WARRENDER

Papers have been contributed to the United Nations Conference on the Application of Science and Technology for the Benefit of the Less Developed Areas as working papers for that Conference. They are published as presented by the contributors, and the contents and the views expressed are those of the contributors. (See notes overleaf.)

NOTES

1. Papers selected for inclusion in General Sessions will be available at the Conference in the following official languages of the United Nations: English, French, Russian and Spanish.

2. Papers selected for inclusion in Specialized Sessions will be available at the Conference in only one of the above official languages.

3. Summaries of all papers, as submitted by contributors, will be available at the Conference in the following official languages of the United Nations: English, French, Russian and Spanish.

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LIMITING FACTORS IN THE MECHANISATION OF MINES UNDER CONDITIONS PREVAILING IN LESS DEVELOPED AREAS

David L. Warrender.

1. INTRODUCTION

This paper is based on the author's experience in the Enugu coal mines of the Nigerian Coal Corporation, and a general description of the coalfield and conditions therein, while not essential to the subject matter, is included in the paper, as it is felt that this may help the reader to gain a better understanding of the conclusions drawn. Again, it is not the author's intention to compile masses of statistics, but simply to give his opinions, along with the reasons for same, based on practical knowledge and experience.

The coalfield is situated in the Eastern Region of Nigeria in close proximity to Enugu, the capital of the region, which owes much of its growth to the coal industry. The coal seams, geologically speaking, are of fairly recent origin, and have not yet been extensively proved, except in the area of outcrop along which the mines are situated. Coal mining began in the year 1916, and at that time was under the control of the Nigerian Railways, as the coal was mined principally as a fuel for steam locomotives. Nowadays, the responsibility for mining the coal rests with the Nigerian Coal Corporation, which operates four mines. Output is in the region of 650,000 to 700,000 tons per annum, and is mainly supplied to Nigerian Railways and the Electricity Corporation of Nigeria for use in power stations, although an increasing market is gradually being developed with smaller industries, such as cement factories, canning factories etc. and some coal is exported to Ghana. Although six different seams have been proved, only one is of workable thickness. The seam being worked varies in thickness between 4'0" and 7'0" and is troubled by slight undulations, although generally it can be considered as flat.

The mines worked at present are situated along the outcrop of the seam, and the coal is worked from surface drifts driven into the hillside along which the outcrop occurs. The workings themselves are relatively shallow, the depth from the surface rarely exceeding 500 feet and more often in the nature of 200 ft. to 300 ft. Due to the shallowness of the working, no great roof pressures are experienced. The labour used in the mines comes entirely from the local population, and the supervisory and technical staff was previously composed mainly of expatriate officers, but in recent years, most of the responsibility for management and administration has been taken over by experienced and qualified Nigerian technicians, many of whom have received overseas training, after gaining initial experience locally.

2. THE APPLICATION OF MECHANISATION UNDER THE PREVAILING MINING CONDITIONS

The term, prevailing mining conditions, is intended to include geological conditions, suitability of the present systems of working for adaptation to mechanised mining, capacity of officials and workmen to learn new techniques and the marketing requirements with regard to size and quality of the product. Before any decision can be taken with regard to the introduction of mechanisation, a detailed survey must be undertaken to decide:

(a) The types of machinery and the method of working best suited to conditions. The knowledge and experience for making this decision is not normally available in less developed areas, as mining practice is progressing at such a rate in more advanced countries, that the mining engineer overseas finds it increasingly difficult to keep up to date with modern methods. Recommendations must therefore be obtained from a body which is specialised in this field.

(b) Reconstruction work which may be required at existing mines, particularly with regard to haulage and ventilation systems, before the benefit of complete mechanisation would be felt.

(c) The need for laying out a new mine or mines. It may be possible, by the introduction of extensive mechanisation, to delay or even cancel the development of new mines, which have been scheduled for the increase or maintenance of output.

(d) The need for screening and washery plant depending on the requirements of the market.

The application of mechanisation would normally proceed slowly initially for the following reasons, firstly, there is a shortage of technicians to work and maintain machinery on a large scale. Secondly, there is a shortage of trained supervisory staff to enable mechanised mining to be operated successfully. Thirdly, the workmen themselves must be trained in new methods. All these considerations may be overcome by the importation of trained personnel for a limited period, but the cost of maintaining such a group of specialists may well prove to be prohibitive, unless subsidised from outside sources.

3. ECONOMIC CONSIDERATIONS

It must be assumed that mechanisation will only be introduced for one of the following reasons:

(a) To reduce the cost of production by increasing efficiency and reducing labour costs. If mechanisation is introduced purely to reduce the cost of production, and assuming that no overall increase in production is required, then the following factors have to be considered:

(i) The amount of capital outlay required. This would vary considerably depending on the type of machinery required and reconstruction work which might need to be carried out at older mines. With special regard to coal mines, it is an established fact that the percentage of small coal and fines increases with face mechanisation, and if a dirt-band occurs in the seam, the amount of stone in the run-of-mine product again increases. This would require additional capital expenditure on coal screening and washery

machinery where these are not already established.

(ii) Additional staff will have to be employed and trained for machine maintenance and overhaul. Power costs, which are often very high in a rapidly developing country must be considered. All machinery and spares for such machinery must be imported. This will involve high freight charges, and also means that the stock of spare parts normally held by agents or manufacturers, must be stored by the mining concern, which again means capital outlay.

(iii) Where there is an extensive mechanisation programme visualised, the workers must be thoroughly trained to operate and maintain the machinery if the full benefit of mechanisation is to be gained. This will mean the short-term employment of a team of experienced, practical instructors and demonstrators, whose services will not come cheaply.

(iv) All of the foregoing items must be set against the saving in labour costs gained by the increase in efficiency and consequent redundancy of labour. In a less developed area, the wage rate per unit of production is low compared with more developed area, and will not increase to any great extent until the area becomes fully industrialised, with resultant full employment. Experience has shown that the economic advantage gained by the introduction of mechanised mining is almost wholly offset by the increase in maintenance and running costs.

(b) To increase production from a given number of mines. The main economic consideration in this case, is whether the development of a new mine would cost less than the concentration of output from existing mines, by the introduction of mechanisation.

(c) A combination of (a) and (b) which would be associated with long term planning and with the development of new mines. This category would come under long term planning on a national scale, and in the case of coal mining, would be based on an intensive industrialisation policy. The controlling factors would then be the availability of sufficient capital, and the rate at which output would require to expand to keep pace with the fuel requirements of industry.

4. SOCIOLOGICAL CONSIDERATIONS

The social consequences of any mass redundancy of labour in a well established industry, where alternative employment is not available and where no form of social security is in operation can be well imagined. The immediate effects may be mitigated to some extent by the payment of some gratuity or ex-gratia payment, which would be added to the cost of mechanisation, but eventually, the remainder of the community must absorb and support the retrenched labourers. This inevitably means a reduction in the standard of living of the community as a whole.

One of the more important, and at the same time, uncertain aspects of introducing mechanisation in mining, is the need for good industrial relations between men and management. Miners are a very conservative group when faced with new ideas and techniques, and good industrial relations must exist if anything new is to be introduced successfully. Good industrial relations can only exist if the management is fully acquainted with, and sympathetic towards local customs

and traditions. Therefore, the management should consist of people who are native to the area, or who have spent a considerable time living and working in the country.

5. TRAINING FOR MECHANISATION

This is the most important factor in introducing mechanisation. The training programme must be carefully and expertly prepared and may be divided into the following categories:

(a) Training of Labour. The basic training of the labour force must of necessity be carried out on the job by experienced practical demonstrators and supervisors, and should consist, at least initially, of step by step instruction in a rigid and timed system of working, which has been planned beforehand. The training programme may also be supplemented by mass lectures and film shows, showing how the machine should work and the various stages of the work.

(b) Training of Engineering, Maintenance and Repair Staff. Modern mining machinery and controlling apparatus is very often of a highly complex nature, and every engineer who is in any way responsible for maintaining or repairing such machinery, must have a basic theoretical knowledge of his particular branch of engineering. Before this knowledge can be assimilated and understood, he must have a good background of general education. This background which should be up to Secondary Education standard, will often be lacking in a less developed area, and presents one of the main obstacles in the whole scheme. The training of the craftsmen must therefore begin a considerable time before the introduction of mechanisation takes place. The practical side of the instruction course will again be carried out on the job.

(c) Training Supervisory Staff. Again, the instruction would be mainly practical, with a series of lectures, mainly pertaining to safety. It would be of considerable advantage if these instructors and demonstrators could have some knowledge of the language and local customs. In other words, if they could consist of people who already have mining experience in this particular area.

(d) Training of Management and Executive Staff. Mechanisation brings with it into top management, a series of highly specialised jobs in all departments, and training for these jobs can only be obtained in an area or country where mechanisation is already accepted practice, unless the introduction of mechanisation is to be a relatively slow process.

6. THE NEED FOR A GUARANTEED MARKET, PREFERABLY CLOSE TO THE COALFIELD.

As the introduction of mechanisation in mining will be part of a long term policy, due to the amount of capital expenditure involved, it follows that this money will not be spent unless there is a guaranteed return of capital from the sale of the mineral produced. In the case of coal which is faced with growing competition throughout the world from other sources of fuel, in particular fuel oil, the proximity of the consumer to the coalfield is of the utmost importance, for two reasons, mainly the excessive cost of freight charges for the bulk transportation of the mineral, and very often, the uncertainty of the facilities for long-distance haulage in less developed areas. Where there has already been a considerable amount of industrial development in the area, the market will be already established, but if mechanisation is being contemplated in the hope of expanding the market, then there must be a guarantee that coal consuming industries

will be introduced, and that they will continue to use the mineral as a fuel over an extended period. This may only be accomplished as the result of having nation fuel and industrialisation policies which are closely linked.

7. FUTURE PLANNING

Planning for the future of any mining area will be considerably altered by the decision to introduce mechanisation, viz.

(a) Planning of New Mines. With the concentration of output that mechanisation will bring, it should be possible to increase the output from existing mines, or to maintain the existing level of output from fewer mines. In either case, it will very probably entail the postponement of plans for the development of new mines.

(b) Planning New Systems of Working. New methods of working the mineral will be employed, and this must mean re-planning of existing and future district layouts.

(c) Planning New Training and Educational Schemes. Too great an emphasis cannot be placed on the need for proper training of all grades of workers in the industry, from labourers to the top executive ranks. All existing training schemes will require to be re-organised, and new schemes instituted where necessary to cope with the new trends and ideas.

(d) Planning for New Markets. Mechanisation in the coal industry brings with it a degradation in the size of the end product. Existing markets must be warned of any impending changes and new markets have to be introduced which will use the type of fuel available.

(e) Planning for Extensive Stock-Piling Facilities. Machines can only be economical if they are kept producing. In a fluctuating market, the only means of maintaining a planned output over considerable periods, is to hold sufficient stocks to cushion the differences in demand.

8. CONCLUSIONS

(a) The introduction of mechanisation must be accomplished by meticulous planning, if the full benefits are to be felt.

(b) Where possible, the introduction should be made gradually to allow sufficient time for the workmen to become accustomed to the machines, and in particular, to allow maintenance staff to receive proper instruction.

(c) The main considerations will be of an economic nature, but the introduction of mechanisation should not be allowed where a large percentage of the labour force may be declared redundant, if alternative employment cannot be made available. At the same time, the availability of a disciplined labour force may influence the setting up of new industries.

(d) The introduction of mechanisation requires the expenditure of a vast amount of capital, and guaranteed markets with expected returns over long term periods must be foreseen.

(e) Although complete mechanisation may not be considered expedient, mechanisation should be carried out on underground haulage and conveying systems, particularly at bottlenecks, in order to eliminate delays due to the human factor.

(f) Mechanisation would also be recommended in the development of new mines, where speed means money, in the sense that the mine would become a productive unit more quickly.

(g) The design of the machinery and control apparatus should be kept as simple as possible, at the same time, complying with local conditions and safety regulations.

(h) Where the mining concern or company is not very large, the output from one machine may represent a considerable portion of the total output, therefore, if the machine is to be kept working at maximum output, a stable market is essential, unless considerable stocks of the mineral can be held. This may not be possible, if for instance, the product is subject to rapid deterioration.

(i) Training in general for all personnel, from labourer to executive, should be carried out under local conditions, although a certain amount of intensive overseas training may be unavoidable, particularly with regard to the specialist jobs such as planned maintenance, cost control and management techniques, which follow mechanisation.

(j) Where mechanisation is envisaged in the future, experiments with various systems of working and roof control should be instituted, and as much factual data as possible accumulated against that time.

(k) Every effort should be made to instal any piece of machinery or equipment which improve the health, safety and working conditions of the workmen.

NOTE: The opinions expressed in this paper are those of the author, and are not necessarily those of the Nigerian Coal Corporation.

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